BOYE'S
PNEUMATICS

Thomas J. Turner

1858

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TREATISE

ON

PNEUMATICS:

BEING

THE PHYSICS OF GASES,

INCLUDING VAPORS.

CONTAINING

A FULL DESCRIPTION OF THE DIFFERENT **AIR PUMPS**, AND THE EXPERIMENTS WHICH MAY BE PERFORMED WITH THEM; ALSO THE DIFFERENT **BAROMETERS**, PRESSURE GAUGES, **HYGROMETERS**, AND OTHER **METEOROLOGICAL INSTRUMENTS**, EXPLAINING THE PRINCIPLES ON WHICH THEY ACT, AND THE MODES OF USING THEM.

Illustrated by Numerous Fine Wood Engravings.

BY

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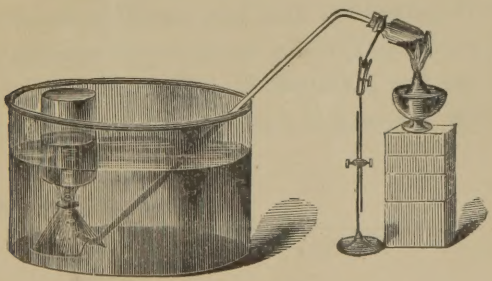

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PREFACE.

THE frequent inquiries made in regard to the principles, different constructions, and modes of using the different meteorological instruments, which come within the subject treated of in this little volume, and the general and increasing interest felt in these matters, induce the author to believe that the present work will supply a want which has been much felt. While he has adhered to a strict systematic arrangement, and, on the part of science, sacrificed nothing to *popularity*, he hopes that he has made the explanations so clear and full as to be intelligible to all. Nor has he spared any trouble or expense in illustrating the subject by numerous appropriate wood-cuts made expressly for this work, and many of them entirely original. For the use of the different instruments a series of Tables has been added, including those of the Tensions of Vapor of Water, used with the Boiling-Point Barometer and the different Hygrometers, which Tables have been calculated for this work from those of Regnault, and are here given, for the first time, complete in English measures and Fahrenheit degrees.

PHILADELPHIA, *May* 16*th*, 1855.

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ON INANIMATE MATTER.

ON

INANIMATE MATTER.

GENERAL INTRODUCTION.

1. By Matter we understand all that acts on our senses. Matter, therefore, constitutes the whole external or Material World, the Universe. Our knowledge of matter systematically arranged constitutes the Sciences of Matter, or the different Material or Natural or Physical Sciences, or Physics in its widest sense; in contradistinction to the sciences of the mind, or the Mental and Moral Sciences, treating of the internal or immaterial world.

2. The different phenomena and properties of matter we account for by ascribing them to certain causes inherent in matter itself, which we call Forces. These forces are always found to act according to certain rules or laws. The main object of the physical sciences must, therefore, be to discover these forces, and expose the laws according to which they act.

3. But besides the general forces, which all matter obeys at all times, matter is also capable of being brought under a peculiar influence, which we call Life. While under such influence it is called Animate matter, in contradistinction to which, when not under this influence, it is called Inanimate matter. We therefore get two main branches of the physical sciences: Physics of Animate matter, or Physiology (Special Physics), which treats of Life and the manner in which matter is influenced by it, or of Animate matter; and Physics of Inanimate matter (General Physics), which treats of Inanimate matter.

4. Our knowledge of inanimate matter must refer either to its place, or to its nature; we therefore get two divisions of Physics of Inanimate

matter, Physics proper, or Natural Philosophy, which treats of the place of inanimate matter, and Chemistry, which treats of its nature.

5. The physical sciences have each their descriptive part, describing the different objects or bodies formed in nature by the forces or influences of which they treat. These descriptive parts are often considered as separate sciences, and called the sciences of Objects, in contradistinction to which the others, of which they are only descriptive parts, are called the sciences of Phenomena. Thus the descriptive part of Physiology, or a description of all the different forms of matter assumed under the influence of life, or animate objects, constitutes Natural History, of which again Anatomy is a subordinate branch. Uranography is a descriptive part of Physics, Mineralogy of Chemistry, and Geology, Meteorology and Physical Geography, are descriptive parts of Physics and Chemistry.

6. The above main branches and divisions of the natural sciences, when applied to particular purposes, as the performance of certain mechanical operations, or the production of certain chemical compounds, required for our necessities or comforts or other relations of social life, constitute the different applied, or practical, or industrial sciences. These are used in the different trades, manufactures and arts, and a systematic arrangement of the greater number of them is often called Technology. Agriculture, Surgery, Medicine, &c., are instances of applied branches of Physiology, in connection with Physics and Chemistry.

7. The different economical, political and philological sciences are combinations of mental and physical sciences, pure or applied.

DIVISION I.

PHYSICS PROPER, OR NATURAL PHILOSOPHY.

INTRODUCTION.

8. PHYSICS proper, it has been said in a general way, treats of the place of matter. But as we account for all phenomena connected with matter by ascribing them to certain causes inherent in matter, which we call forces, which forces always act according to certain rules or laws, Physics proper must treat of the forces, by which matter holds its place in space, and expose the laws according to which they act.

9. That which first strikes us in regard to the place of matter on a large scale, is, that we do not find it to be equally distributed through space, but collected in large masses, constituting the heavenly bodies and the earth, and the space between them to be comparatively void.

10. We have reason to believe, that internally matter is constructed on a similar plan, so that any portion of it does not consist of matter uniformly diffused through the space which it occupies, but that the matter of which it consists is collected in small particles called atoms, with a small space between them, which is comparatively void. These ultimate particles or molecules are called atoms (from *α* privative and *τεμνῶ* (temno) I cut), meaning what can not be cut or divided, because they are considered to be indivisible and indestructible. Though practically they may be considered infinitely small, still in reality they have a certain definite size and form. Their form is generally considered to be that of small solid spheres or spheroids, inside perfectly uniform; single spheres for simple bodies and clusters of such spheres for compound bodies.*

* The main arguments in favor of the existence of atoms with spaces between them are: the general nature of chemical combination with the laws of definite and multiple proportions, isomerism and allotropism, for which see under Chemistry; cleavage and crystallization, see under Stereotics; expansibility of gases, see Pneumatics; the

11. All bodies, by which we understand limited portions of matter, must therefore consist of aggregations of such atoms. These atoms being not in contact are kept at certain extremely small but definite distances from each other by two forces, an attractive force, which tends to approach them to each other, and a repulsive force, which tends to separate them. The resulting effect of these two forces is called COHESION, and constitutes the force with which each atom is held in the same relative position to the other atoms of the same kind of matter. Compressibility and Elasticity are properties of matter depending on this same force.

12. According to the greater or less strength of the above attractive and repulsive forces between the atoms, constituting the degree of cohesion, matter presents itself in one or the other of the following three states or forms.

1st. *The solid state.* Whenever the attractive and repulsive forces between the atoms are great, the atoms are kept firmly in their relative position, so that they offer considerable resistance to any force that tends to move them among themselves, or to separate them from each other. In this case, therefore, the cohesion is said to be great, and the matter presents itself in the solid state.

2d. *The liquid state.* In this state matter presents itself when the attractive and repulsive forces between the atoms are but small. The atoms are then held in their relative position with but a slight force, so that they can easily be moved among themselves, or separated from each other. In liquids, therefore, the cohesion is small.

3d. *The gaseous state.* This state matter assumes when the atomic repulsive force is greater than the attractive. The atoms then have a tendency to separate from each other and spread themselves through space, unless prevented by some other cause. This property in gases is called Expansibility, and distinguishes them from liquids. Cohesion in this case is said to be negative. They also offer little or no resistance to the motion of their particles among themselves, in which point they resemble liquids. For this reason liquids and gases are comprised together under the common name of fluids in contradistinction to solids.

13. One and the same kind of matter may often, under different circumstances, exist in either of the above three states. Thus water when exposed to cold becomes solid or ice, and by heat may be converted into gas or steam. But matter can only exist in one state at the same time, and under the same circumstances it nearly always assumes the same state.

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expansion of all matter by heat, see Thermics; and the undulatory nature of light, and its passage through all forms of ponderable matter, see Photics. For the particulars regarding the form, size and weight of atoms, see under Stereotics.

14. *The ethereal state.* The existence of a fourth state of matter is rendered highly probable, filling the spaces between the atoms of the above three states (the interatomic spaces), and the spaces between the planets and between the stars (the interplanetary and interstellar spaces). This state is called the Ethereal, and the matter itself Ether.* That Ether must differ materially from other states of matter, follows from the fact, that it fills the spaces between their atoms. Either therefore it can not be composed of similar ultimate atoms, or these atoms must at least be of a much smaller size. As it has been found to offer a sensible resistance to the comets in their motion, it must, as it will afterwards be understood, possess inertia and in this point resemble the other kinds of matter. If, however, it is affected by gravity so as to possess weight, (see further on), this is so inconsiderable, that it cannot be ascertained by the same means by which it is proved for other matter, hence it is generally called Imponderable matter, in contradistinction to which the other states of matter are called Ponderable matter. It has not been ascertained whether other states of matter may also exist in the Ethereal state, or the Ether itself be condensed or converted into the others. On the whole, though its existence is well established, our knowledge of its nature is yet but very imperfect.

15. The same attractive and repulsive forces, which exist between the atoms of matter of the same kind, we also find between the atoms of different kinds of matter, by which these are held in their relative position at a small distance from each other. The resulting effect is in this case called ADHESION, because if after having brought the atoms of two different bodies together, we again attempt to separate them, particles of the one often remain by this force attached, or adhere to the other. Thus if we dip a glass rod into water and then again withdraw it, some of the water will adhere to the glass in preference to cohering to the other particles of itself. Capillary attraction and solution are caused by the same force.

16. The attractions and repulsions, of which we have spoken (Cohesion and Adhesion), do not extend perceptibly beyond a very small distance, probably not beyond the distance of proximate or neighboring atoms. We observe, however, another attractive force to exist between atoms of the same or different kinds of matter, and acting also at distances greater than the distances of proximate atoms, only in a certain diminishing ratio.

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* The main argument for the existence of Ether in all these spaces and others, not filled with ponderable matter, we have in the passage through them of light, which can be proved to be formed by undulations, which therefore require the existence of an undulating medium.

As it thus acts on all the atoms, of which a body consists, and at great distances, it becomes also an attraction between masses of atoms, or bodies towards each other. This attraction is called GRAVITY, and must therefore be greater according to the number of atoms in the different bodies. We thus find that a very strong attraction exists by gravity between the heavenly bodies and the earth, and between the earth and all terrestrial bodies on or near its surface; but it is exceedingly small between the terrestrial bodies themselves, though it can be proved also to exist between them according to their size. Gravity has by some been considered as the result of the attractions of cohesion and adhesion, but this is not probable; at all events we are not acquainted with a corresponding repulsive force acting at a distance like Gravity.

17. It has been stated that the ultimate atoms are considered solid. They therefore allow no other atoms of the same, or any other kind of matter to enter or occupy the same space at the same time. This property of matter is called IMPENETRABILITY. The space between the atoms may be diminished (Compressibility), but the atoms of the same body can never be forced into each other even by the greatest pressure, nor will they allow the atoms of any other body to be forced into their place. One kind of matter may, however, allow the atoms of another kind to penetrate with considerable facility into the spaces between its atoms, while it will resist with great force the further approach of its own atoms. This property is called Diffusibility, and depends on the attraction, which has been spoken of before as Adhesion, and is particularly observed between the atoms of solids and liquids, and also between the atoms of different kinds of gases.

18. When matter has been influenced by a force to move, and in its way meets other matter, so that it can not continue its motion without putting this matter also in motion, we find this latter to take place, and a portion of its own motion to be transferred to it. We thus find, that motion is transferable by IMPACT or IMPULSE from one portion of matter to another.

19. Matter has also an inherent force to preserve its state of rest or motion. This force or property of matter is called INERTIA, and is generally expressed thus, that matter when at rest cannot by itself begin motion, nor when in motion can it alter this so as to pass to rest, or to a slower or faster motion, or in a different direction, unless influenced by some other cause.

20. With the idea of matter and its existence is necessarily given the idea of space to exist in. Where one kind of matter ceases and another begins, there must be a limit, and all limited portions of matter, or bodies, must therefore have a *Form*. But the abstraction of space and form from

matter, and its separate consideration can only be made in the mind, and constitutes, therefore, a purely mental science, Geometry, which does not belong to the natural sciences, while the application of its results to the forms of matter, as they actually occur in nature, is of the utmost importance to them (Crystallography, &c.). The same is the case with the abstraction of the idea of repetition of separate but like portions of matter or *Numbers*, and their separate study, which constitutes Algebra, and in its application is of equal importance to the natural sciences.

21. Matter, while it by its own inherent forces influences other matter and itself to motion, is equally susceptible to the forces of all other matter, and will move under their influence. The influence of a single force is to move it in a straight line. But as it is always acted on at the same time by a number of forces, and has to move according to all of them, its motion is always more or less complex. If at the same time matter be influenced by different forces to move equally in opposite directions, it will retain the same place or be at rest. Though experience teaches us that all matter is in constant motion, no particle retaining the same place for any length of time, so that there is no absolute rest, still a body may be influenced so as not to alter its position in regard to surrounding objects, and we then generally say, that it is at rest, though it is only relative or apparent rest.

22. As the amount of matter in existence always remains the same, and matter, therefore, cannot be destroyed any more than created, the amount of its inherent force to produce motion, and the effects produced by it at any moment must also remain the same. Applying this to the forces producing motion, it follows from this and what has been said of Inertia, that motion can no more be destroyed or created than matter itself; and as all matter is now in constant motion, motion must be coeval with matter.

23. The forces and properties of which we have spoken so far (Cohesion, Adhesion, Gravity, Impenetrability, Impact and Inertia), are the main causes due to ponderable matter itself, on which depends its position in space. There are yet other attractions and repulsions between the atoms and masses of ponderable matter, such as the expansion by heat, the attractions and repulsions by electricity, &c.; but these seem to be connected with or imparted to it, by certain states or motions of the ether between its atoms, and the causes of which are designated as light, heat, magnetism and electricity. They will, therefore, be treated of separately in connection with the ether. We thus obtain two parts of Physics proper, Physics of Ponderable matter, or Mechanical Physics; and Physics of Imponderable matter, or Ethereal Physics, which treats of the ether, and the influences it exercises on ponderable matter. Physics of Ponderable

matter we again subdivide into three sections; Physics of Solids, or Steoretics; of Liquids, or Hydraulics; and of Gases, or Pneumatics. Physics of Imponderable matter is sub-divided into four sections; Physics of Light, or Photics, or Optics; Physics of Heat, or Thermics; Physics of Magnetism, or Magnetics; Physics of Electricity, or Electrics. The following table will exhibit the respective divisions and subdivisions of the Natural Sciences.

- PHYSICAL OR NATURAL SCIENCES. (Physics in its widest sense.)
  - Physics of Inanimate Matter. (General Physics.)
    - Physics proper, or Natural Philosophy.
      - Physics of Ponderable Matter. (Mechanical Physics.)
        - Physics of Solids, or Stereotics.
        - Physics of Liquids, or Hydraulics.
        - Physics of Gases, or Pneumatics.
      - Physics of Imponderable Matter. (Ethereal or Imponderable Physics.)
        - Physics of Light, or Photics, or Optics.
        - Physics of Heat, or Thermics.
        - Physics of Magnetism, or Magnetics.
        - Physics of Electricity, or Electrics.
    - Chemistry. (Atomic or Chemical Physics.)
  - Physics of Animate Matter, or Physiology. (Special Physics.)

PART I.

PHYSICS OF PONDERABLE MATTER.

Though in a systematic point of view it would be better to treat first of solids, still as it practically is more important, first to have a knowledge of the physical properties of gases, we shall begin with these.

SECTION I.

PNEUMATICS, OR PHYSICS OF GASES.

The word Pneumatics is derived from a Greek word πνευμα (pneuma), signifying air.

Properties of gases depending on Cohesion.

24. We have seen that whenever the repulsive force between the atoms preponderates over the attractive, matter assumes the state called the gaseous or æriform. Gases, therefore, not only possess fluidity like liquids, that is, they offer but a slight resistance to the moving of their particles among themselves, but their atoms have also a constant tendency to recede from each other, and therefore to extend themselves over space, until limited or confined by some outer boundary, or restrained by some counteracting force. This property is called *Expansibility*, and constitutes the main difference between gases and other states of matter.

25. Nature has placed us in an ocean of gases called the Atmosphere, which forms the uppermost portion of the whole earth. Thus circumstanced, we are apt to feel less conscious of their material existence and to overlook the fact, that they form the medium, through which we generally receive the impressions on our senses from other bodies. Thus when we hear a sound caused by the vibrations of a solid, it is not these latter that act on our ears, but the vibrations of the air produced by them. And if, in the same manner, on account of the extreme fluidity and tenuity of the

atmospheric gases, they under ordinary circumstances are not perceived, we may easily render air as tangible as a solid or liquid by allowing it to impinge against any part of our body; for instance, by blowing on it. And even to our eye-sight air is as visible as any other kind of transparent matter; we have colored gases, and a bubble of a colorless gas is as visible in water, as a drop of water is in air. Their effect on the senses of smell and taste is also familiar. It will also be shown, hereafter, that we are capable of weighing gases like any other forms of ponderable matter.

26. Atmospheric air is, however, not one kind of gas, but a mechanical mixture of four different gases. Oxygen, about $\frac{1}{5}$ by vol., and Nitrogen, about $\frac{4}{5}$, or more accurately, in the relative proportion to each other of 20.8 ox., to 79.2 nitr., form the main portions of it. Besides these it contains small but varying quantities of Carbonic acid (about $\frac{1}{2}$ per mille), and Vapor of water ($\frac{1}{2}$ to 2 per cent.).

27. On account of its expansibility it might be supposed, that the atmosphere surrounding the earth would extend itself infinitely far into space. This is, however, not the case. We can prove from the property of refraction, which the atmosphere possesses, or that of bending the light from its straight path, when penetrating in an oblique direction through its strata of different densities, that it does not extend sensibly beyond the height of 45 miles. It is therefore probable, that as the rarefaction of the atmospheric gases increases with the distance from the earth, their expansibility also becomes less, and is at last overcome by gravity, drawing them toward the earth, so that where these two forces are equal, they will assume a definite limit. This is confirmed by the experiments of Faraday, according to which the vapors of mercury enclosed in a tall jar, only rise to a certain height, presenting an upper level surface. If this be correct, the different gases of which the atmosphere is formed, ought to assume each a separate level at different heights from the surface of the earth, according to their different densities. This might, however, be prevented by the commotion caused by currents.

28. The expansibility of gases affords us the means of removing them from any containing vessel, or of rarefying them to any extent. Apparatus constructed for this purpose are called *exhausting air-pumps*. In the simplest form an exhausting air-pump consists of a single hollow cylinder, generally of brass (see *a figs.* 1 and 2), called the barrel, and having the inside ground perfectly true, so that a short solid cylinder *b*, called the piston, may be moved in it perfectly air-tight by the aid of the piston-rod *c*, furnished for this purpose with a handle *d*. At the bottom of the barrel is an orifice, which forms the beginning of a passage, (see *fig.* 1 and *e fig.* 2), which at its other extremity is furnished with a

Fig. 1.

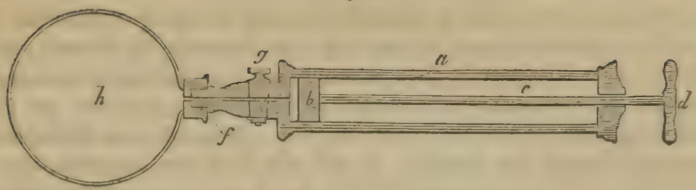
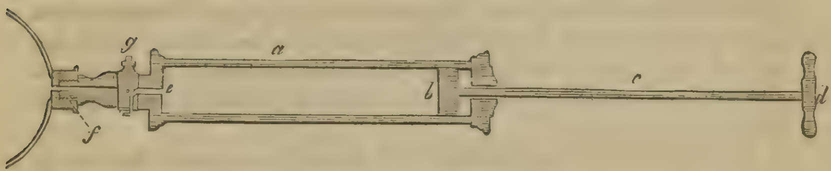


Fig. 2.



screw *f*, by which it can be attached to any vessel or receiver *h*, from which it may be desirable to exhaust the air. Across this passage *e f*, as near as possible to the barrel, is inserted a conical piece of metal *g figs.* 1 and 2, and represented separately by *fig.* 3, called the plug, fitting across the passage in a corresponding conical hollow, so as to be movable round its axis, which is at right angles to the passage; the whole, the passage with its conical hollow and the plug, constituting a stop-cock. The plug of a stop-cock has always one perforation through it, which in one position forms a continuation of the passage; but when the plug is turned 90 degrees round its axis, so as to have the perforation at right angles to the passage, this is interrupted. The stop-cock used in this case is what is termed a two-ways stop-cock, having two perforations, see *fig.* 3, the usual one *i* to close and interrupt the passage *e f* between the barrel and the receiver *h*, to which the air-pump is attached, see *fig.* 1, and a second one *k fig.* 3, which when the first perforation is at right angles to the passage, see *fig.* 2, forms at first a continuation of it, but then turns so as to run parallel with the axis of the plug, and terminates outward into the atmosphere, thus establishing a communication between the barrel and the outer air, when the communication with the receiver is shut off, as seen in *fig.* 2, which, however, is interrupted when the communication with the receiver is open, as seen in *fig.* 1.

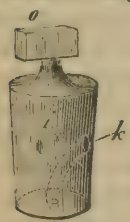


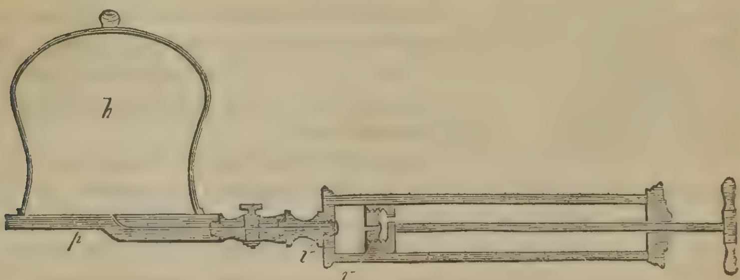
Fig. 3.

29. If now after having attached the air-pump to any vessel or receiver *h*, from which we intend to exhaust the air, and having turned the

stop-cock *g*, so as to establish a communication between it and the barrel, see *fig.* 1, we draw out the piston as represented in *fig.* 2, the air in the receiver will expand and fill both the receiver and the barrel. The stop-cock is then turned so as to shut off the communication between the receiver and the barrel, and to open it between the barrel and the outer atmosphere, as represented in *fig.* 2, and the piston pushed in to the bottom of the barrel, by which the air in the barrel is expelled into the atmosphere. If then again by turning the stop-cock, the communication be interrupted between the barrel and the atmosphere, and opened between the barrel and the receiver, and the piston drawn out, and the same process repeated, a portion of air will by every outward stroke of the piston enter from the receiver into the barrel, and by the next inward stroke be expelled into the atmosphere. This might thus be continued as long as the remaining air retains its expansibility, though a last portion, however small, would always remain behind. Practically, however, it is not possible to carry the exhaustion this far; for, however near the plug of the stop-cock be placed to the barrel, a small space will always remain between it and the bottom of the latter, called the *Injurious Space*, into which the piston cannot enter. After the piston has been pushed to the bottom to expel the air in the barrel into the atmosphere, this space will always remain filled with air of the same density as the atmosphere. If this air which thus remains in the injurious space, by expanding over the barrel when the piston is again drawn out, be yet of the same density as the remaining air in the receiver, none of the latter can enter into the barrel, when the communication between them is established, and thus all further exhaustion becomes impossible. Besides this, such apparatus are often apt, from imperfect make, to admit small portions of air by leakage.

30. Stop-cock pumps have the inconvenience, that the stop-cock must be turned at every stroke. This may be performed by mechanical contrivances connecting it with the motion of the piston-rod, and they then con-

Fig. 4.



stitute very superior pumps. It is, however, more convenient and less expensive to substitute pneumatic valves, which are self-acting. Such valves are generally constructed of a strip of oil-silk, see v and v^1 *fig.* 4, and v *fig.* 5, fastened by its two extremities, so as to lay close over the orifice by which the passage terminates, or when the valve is placed in the passage itself, the latter is made to terminate by an orifice s in a projection, over which the oil-silk v is tied or otherwise fastened, as shown by *fig.* 5, which represents separately the valve-piece screwed into the piston of *fig.* 4. Such valves will then allow the air to pass in the one direction between it and the orifice, but as soon as the air presses in the opposite direction, the oil-silk is forced close against the orifice and prevents the air from passing in that direction. Instead of the two-ways stop-cock, two such valves are substituted, see v and v^1 *fig.* 4. One v is placed in the bottom of the barrel over the orifice of the passage leading to it from the receiver, so as to allow the air to pass from the receiver into the barrel but not back again. The other valve v^1 is placed in a passage through the piston, permitting the air to pass out through the piston from the barrel into the atmosphere, but not back again. It will thus be evident, that every time the piston is drawn out, the air in the receiver is allowed to pass through the valve v into the barrel, the valve v^1 in the piston remaining closed. When, on the contrary, the piston is pushed in, the valve v between the barrel and the receiver closes, and the air in the barrel is expelled through the valve v^1 in the piston.

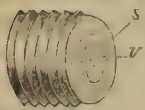


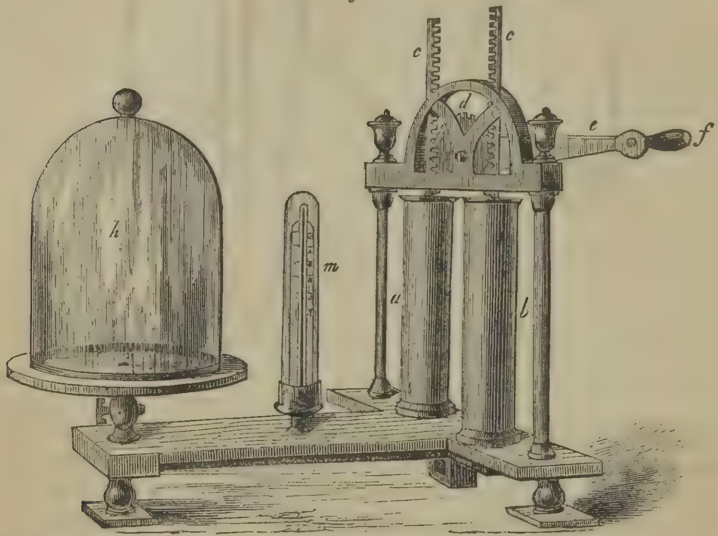
Fig. 5.

31. As it is often desirable to place in the exhausted vessel different objects or apparatus, it becomes necessary to have pneumatic receivers with large mouths or openings. They are then generally made bell-shaped or cylindrical, closed at the top, see h *fig.* 4, but open at the other extremity, the edge of which is ground true, so as to fit air-tight on a brass or glass plate p, also ground perfectly plane, and having an opening in its centre leading to a passage furnished at its other extremity with a stop-cock and a screw, to which the air-pump may be attached. Any object may then be placed on the plate, after which the bell jar, having had its edges greased, is inverted over it and pressed with the edges against the plate, so as to form a perfectly air-tight joint.

32. A single barrelled air-pump, or Syringe, as called when small and worked by hand, always acts unequally, requiring, on account of the atmospheric pressure on the piston (see further on), much more force to move the latter out than back again. To avoid this and also to expedite the exhaustion, which is a tedious process when the capacity of the barrel

is small in proportion to that of the receiver, double-barrelled air-pumps are constructed, see *fig.* 6. These consist of two complete air-pumps, each barrel *a* and *b* having its piston and two valves, one in the piston

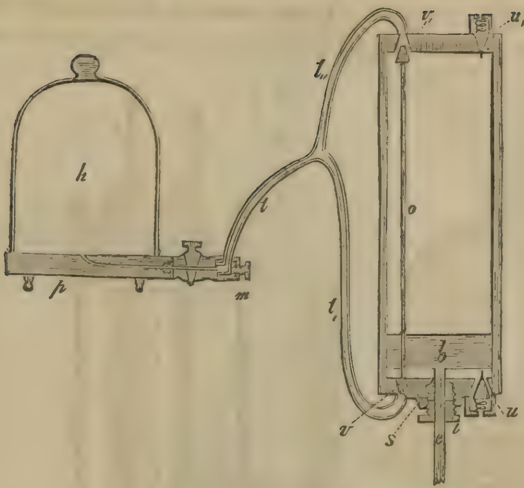
Fig. 6.



and the other at the bottom of the barrel in the passage to the receiver. But these two passages unite into one leading to the receiver *h*, terminating at the plate. The piston-rods are furnished with teeth, so as to form racks *c c*, which are moved by a small cog-wheel or pinion *d*, to the axis of which is attached a two armed lever *e*, with handles *f*. By moving the lever and consequently turning the pinion in alternate directions, one piston is always moved up, while the other is moved down, and thus, while the one barrel is exhausting the receiver, the other is discharging air into the atmosphere.

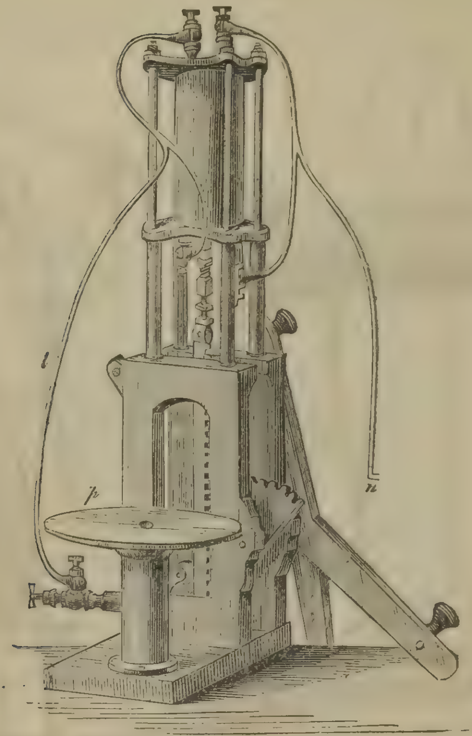
33. Instead of a double-barrelled air-pump, a single-barrelled but double-acting may be used, as represented in *fig.* 7. In this case the cover of the barrel must be air-tight, and the piston-rod made to slide air-tight through it by means of a stuffing box or packing screw. This consists of a hollow cylinder *s fig.* 7, made in the cover round the piston-rod *c*, where it passes through it. Into this stuffing box, the bottom of which has a perforation, merely sufficient to let the piston-rod pass through it without friction, the stuffing or packing is introduced, consisting of oiled hemp or tow, or circular pieces of leather (washers or collars), with perforations through their

Fig. 7.



middle, barely sufficient to allow the piston-rod to be pushed through them. A screw stopper *l*, also perforated through its middle, but so as to allow the rod to pass easily through it, is then screwed down into the stuffing box, so as to force the hemp or leather washers against the piston-rod, so that the latter may slide air-tight through it. The barrel has four valves, u and u_1—v and v_1 which in this case, as always when the pumps are large and subject to constant wear, are made of metal, and have then generally a conical shape, fitting air-tight in a corresponding conical aperture called the valve-seat. By any pressure from the one side, these valves are forced from their seat, while pressure from the other side will force them back again. To restrain their motion and secure their easy return into their seat, they are, in most cases, furnished with a stem, which slides in a cross-piece or guide. As the air when rarified would soon become incapable of opening, by its expansibility, such valves, they must, for exhaustion, as in the present case, be moved by some mechanical contrivance. Of the above four valves, two, v and v_1 open inward to admit the air from the receiver *h* into the barrel, and are worked by a valve-rod *o* sliding air-tight through the piston *b*. The two others, u and u_1 open outward to let the air out from the barrel into the atmosphere, and are held in their places by spiral springs. In order to secure their opening to expel the air, they have a short stem projecting into the barrel, against which the piston strikes, when it arrives near either end. Leading from the valves, v and v_1 which open inward, are two passages, t_1 and t_{11}

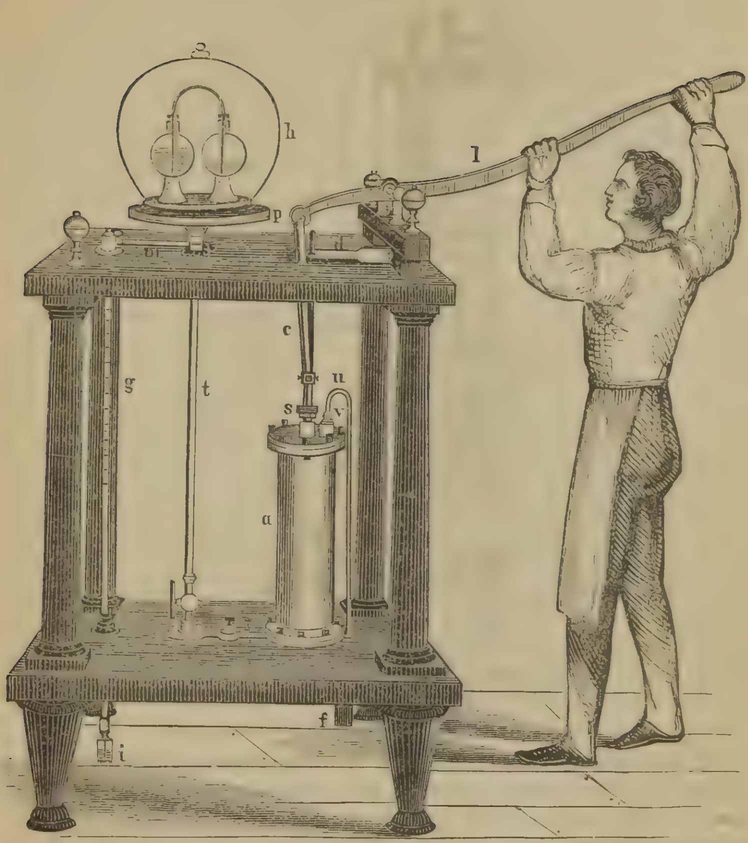
Fig. 8.



uniting into one *t* leading into the receiver *h* through the plate *p*. Being made of lead, and therefore flexible, the tube *t* may easily be connected or disconnected with the plate by a knob and gallows-screw joint *m*. It will easily be seen that by each stroke the piston must, on the one side, draw air in from the receiver, while on its other side it expels the air from the barrel into the atmosphere. *Fig.* 8 gives a full view of a pump of this kind, constructed by Dr. Hare, and used by him for many years in his Laboratory. It has two additional passages leading from the valves *u* and u_1 uniting also into one, open to the atmosphere at *n*. These, however, are not necessary when used only for exhaustion.

34. *Fig.* 9 exhibits another efficient single-barrelled but single-acting exhausting air-pump, of Boston manufacture, often met with, and known as an Improved 'Leslie' Air-pump. The piston-rod c passes air-tight through a stuffing-box s, in the top of the barrel a, its end sliding in a cross-piece or guide d, to keep it perpendicular during its motion; t—t is

Fig. 9.



the tube forming the passage from the barrel to the plate p, into the receiver h. The pump has two valves, one in the piston, opening from the receiver towards the top of the barrel, the other in the top of the barrel at v, opening from this into the atmosphere. These valves are made of circular pieces of thin calf-skin soaked in oil and lard, laying close over the orifices, that at v being fastened on one side by the cap-piece screwed down over it. From this latter valve the tube u, which is removable, leads into a cistern f, open to the atmosphere and intended as a receptacle for the oil, as also for ether, or other volatile liquids, which often have to be removed as vapors from the receiver by exhaustion and may condense in the barrel or the tube, and thus be forced out through it.

When the piston is pushed in, the valve at v prevents the air from entering into the barrel, and a vacuum is formed in the barrel above the piston, into which the air enters, by its expansibility, from the receiver and barrel below the piston through the valve in the latter; when the piston is raised, the air above the piston cannot return through the valve in it, and is forced out through the valve at v in the top of the barrel, while the barrel below the piston is again filled with air from the receiver, following, by its expansibility, the piston as it moves out. This portion of air in the barrel below the piston, will then again pass through the valve in the piston to above it, when this is again pushed in, and by the next outward stroke will be forced out as before. This pump has the advantage over other single-barrelled, single-acting air-pumps, that after the first outward stroke has been performed, all the subsequent ones are, as in the double-acting, performed through the greater part of their motion, not against the atmosphere, but against a partial vacuum, until the piston arrives near the top, when the air becomes condensed to the same density as the outer atmosphere, and of course the last effort to expel it through the valve at v, must be against the whole atmospheric pressure. To carry the exhaustion to the furthest possible limit, the tube u, may be removed and a small exhausting syringe screwed on, by which a vacuum may be produced above the valve at v, by which the injurious space below the same valve will remain filled with air of much less density than the atmosphere, and thus have less effect when expanding in the barrel by the inward stroke of the piston, by which the exhaustion may be carried much further.

35. The amount of air remaining in the receiver at any moment during the process of exhaustion, or the degree of rarefaction, may be calculated, assuming that no leakage takes place, by knowing the relative capacities of the receiver and the barrel. For calling the former R and the latter B, and the ordinary density of the air D, we have after the first stroke, that the air in the receiver fills both the receiver and the barrel, and its density after the first stroke D_1 must therefore be to its former density D, inversely as the spaces occupied, or that $D_1 : D :: \frac{1}{R+B} : \frac{1}{R}$; hence $D_1 = \frac{R}{R+B} D$. After the second stroke we get in the same manner the density $D_2 = \frac{R}{R+B} D_1 = \frac{R}{R+B} \times \frac{R}{R+B} D = \left(\frac{R}{R+B}\right)^2 D$, and at the nth stroke $D_n = \left(\frac{R}{R+B}\right)^n D$. Thus if the barrel have $\frac{1}{9}$ the capacity of the receiver, we have $R = 9$, $B = 1$, and $\frac{R}{R+B} = \frac{9}{10}$, and the density or

quantity remaining in the receiver at the 3d stroke, $= \left(\frac{9}{10}\right)^3 D = \frac{729}{1000}$ of the original density or quantity.

36. The rarefaction at any time is, however, generally estimated by a barometer guage connected with the receiver, see *m fig.* 6 and *g, fig.* 9, the principle of which will be explained hereafter under *pressure-guages.*

37. Suction by the mouth depends on the same principle as exhaustion by an air-pump. The vessel is first connected by the lips with the mouth, and the air then expelled from the mouth by pressing its walls close together. A vacuum is then produced in the mouth by withdrawing the tongue from the roof of the mouth without admitting any air, which constitutes the effort of sucking. The air then passes, by its expansibility, from the vessel into the mouth, as in the barrel of the air-pump. The communication between the vessel and the mouth is then closed by using the tongue as a valve, and the same again repeated.

38. Besides the above means of exhaustion by air-pumps, a partial vacuum may be produced by the increased expansibility of gases by heat. Thus, the suction of an ordinary plain cupping-glass is produced by expelling a portion of the air by heat, by holding it with the mouth downward over a spirit lamp or a piece of burning paper, and then quickly placing it on the skin. Another means of removing atmospheric air from a vessel and thus producing a vacuum, is, by the introduction of a volatile liquid and the application of heat to it, by which it is converted into vapor, which will expel the atmospheric air. By then closing the vessel and allowing the vapors to condense, a vacuum is produced, which is entirely free from atmospheric air, but always contains more or less vapor. Thus, thermometer bulbs, and other vessels with very narrow mouths, are filled with mercury or any other liquid, by first expelling a portion of the atmospheric air by heating them over a spirit-lamp, and then inverting them with the mouth into the liquid. When the air then contracts, a partial vacuum is produced, by which a portion of the liquid is forced up into it by the atmospheric pressure (59). They are then again heated till the liquid inside boils, and its vapour has expelled all the remaining atmospheric air, when they are again inverted with the mouth into the liquid, by which they become entirely filled with the liquid as soon as the vapors condense. The vacuum in the cylinder below the piston of the early or 'atmospheric' steam-engine of Newcomen, was produced by the expulsion of the air by steam from a boiler, and its subsequent condensation.

39. *Compressibility and Elasticity of gases.* From the nature of gases it might be inferred, that the atoms are not so close together as in liquids

and solids. Indeed, we find that the spaces between their atoms are capable of being considerably reduced by mechanical pressure and their volume in consequence diminished. This property is called *Compressibility.* The property of offering to the compression a constantly increasing resistance, and when the pressure ceases, of again resuming their former volume, is called *Elasticity.* Gases thus possess the properties of Compressibility and Elasticity to a much greater extent than either solids or liquids.

40. This is also the reason why we are capable of forcing a considerable quantity of gas into a comparatively small space. Contrivances for this purpose are called *Forcing* or *Condensing Air-pumps.* In its simplest form the Condensing air-pump is identical with the Exhausting Syringe, see *figs.* 1 and 2, consisting of a barrel with a solid piston, and furnished with a two-ways stop-cock, by which it is attached to the receiver, into which the air is to be condensed, only that in using it, the order of turning the stop-cock is reversed. For if the piston be pushed in, while the barrel communicates with the receiver, it is easily seen that the air contained in the barrel must be forced into the receiver. If, now, the stop-cock be turned so as to shut off communication with the receiver, but to establish it between the barrel and the outer atmospheric air, the latter will enter and fill the barrel when the piston is again drawn out. By repeating the same process, a fresh portion of air is by every inward stroke introduced into the receiver, the limit being dependent on the strength of the apparatus and the size of the injurious space (29). For it will easily be seen, that as soon as the air admitted into the barrel may be condensed into the injurious space, without acquiring greater density than the air in the receiver, no more can be forced into it.

41. Instead of the two-ways stop-cock we may, as in the exhausting air-pump, substitute two self-acting valves of oil-silk, see *fig.* 10, one v

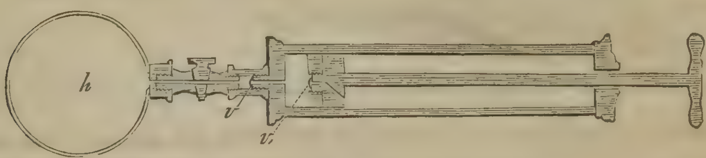


Fig. 10.

at the bottom of the barrel in the passage leading to the receiver, and another v_1 in a passage through the piston, both, however, opening inward as represented in *fig.* 10. The valve in the piston may be dispensed with, and the latter remain solid, if the barrel be furnished with a

small perforation on its side, at a distance from the cover just sufficient to be cleared by the piston when drawn out, for the admission of atmospheric air. On pushing the solid piston in, the air thus admitted into the barrel is confined as soon as the piston has passed the orifice, and forced into the receiver, and so on.

42. Where larger objects are to be placed in the receiver, the latter must be furnished with a wide mouth, see *fig.* 12, the edge of which is

Fig. 11.

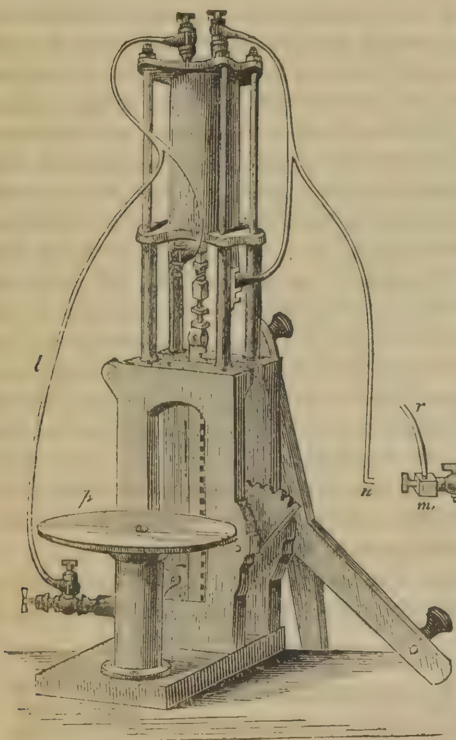
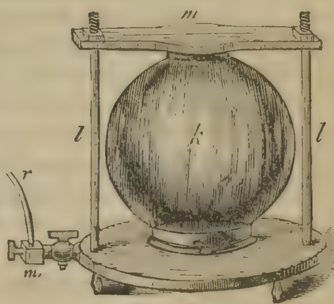


Fig. 12.



ground true and fitted on a plate as for exhaustion, but generally with the interposition of a ring or washer of oiled leather. An additional contrivance also becomes necessary, to keep the receiver against the plate, consisting of two uprights, *l* and *l*, and a cross-piece *m*, which can be screwed down on it, as otherwise the inner pressure of the air would force them apart. Such receivers should also be made as much as possible of a spherical form, and, if of glass, very thick, as much greater strength is

required to withstand a pressure from the inside than from the outside, and by bursting accidents are likely to occur.

43. Where considerable quantities of air are to be condensed, the pump may be made double-acting and its size increased; in which case it becomes necessary to work it by machinery. When high degrees of condensation are required, it also becomes necessary to substitute metallic valves instead of those of oil-silk. The pump *fig.* 7, described in 33, answers admirably for condensing, if furnished with two additional passages leading from the valves u and u_1, as represented by *fig.* 11, which two passages unite into one, terminating in a knob n, so that, being of lead, and therefore flexible, it may be connected by a gallows-screw joint m with the receiver *fig.* 12, into which the air is to be condensed. In this use of the pump the other forked tube t, fixed over the valves, opening inward, must of course be left open, so as to allow the atmospheric air free access through these valves into the barrel. When the piston is moved, atmospheric air is drawn in through the tube t on the one side of the piston, while the air on the other side of it is forced into the receiver through the tube n. Such pump will also answer for transferring and condensing any gas different from atmospheric air. For this purpose the receiver *fig.* 12, into which the gas is to be transferred or condensed, is first exhausted by being connected with the pump by the tube t. It is then to be connected with the pump by the tube n, after the tube t has been connected with the receiver containing the gas to be transferred, and one stroke been performed to expel the atmospheric air from the barrel.

44. It has been ascertained by accurate experiments, which will afterwards be detailed, that the volumes which a gas occupies under different pressures, but otherwise similar circumstances, are inversely proportional to the pressures, and the densities of the gas, therefore, directly proportional to them. This law is called, from its discoverer, Mariotte's law.

45. *Liquefaction of gases.* In regard to their conduct under increased pressures, gases differ materially. Some of them obey Mariotte's law under any pressure which has yet been applied to them, and are therefore called *permanent* gases. Of these we have six; Oxygen, Hydrogen, Nitrogen, Bin-oxide of Nitrogen, Carbonic Oxide and Light Carburetted Hydrogen. Others conduct themselves in a similar manner, obeying Mariotte's law, only until the pressure has been increased to a certain point, when they suddenly yield and are converted into liquids. These are called *liquefiable,* sometimes compressible, or condensable gases, the latter, referring mainly to the fact, that this same effect is assisted by the simultaneous exposure to cold, or may even in some cases be produced by it alone. Of the liquefiable gases a certain number are formed from sub-

stances existing, under ordinary circumstances, as liquids or solids, and when filling the space to their fullest extent, will stand no increase whatever in pressure or cold, without becoming wholly or in part liquid. Such gases are called *Vapors*. As instances of liquefiable gases may be mentioned Sulphurous acid, liquefiable at a pressure of about 5 atmospheres (1 atm. = 15lbs. to sq. in.), and by strong cold alone, and Carbonic acid, requiring 38 atmospheres at 32°. Of vapors may be mentioned vapor of water or Steam.

46. It is supposed that all gases by sufficient pressure would become liquid, but even should this not be the case, it is evident that no pressure, however great, could reduce their volume to nothing, which constitutes their property of *Impenetrability*.

47. To illustrate the compressibility and elasticity of the atmospheric air, fix a burning taper on a cork floating on water. Invert a large tumbler or jar over it, and depress this below the surface of the water. As the depth to which it is immersed increases, the compressibility of the air will allow the water to ascend to a greater height into the jar, but its elasticity will offer a constantly increasing resistance, so that much the greater portion of the jar will still remain filled with the air and allow the candle to continue to burn.

48. On this depends the action of the *diving-bell*, which consists of an open inverted box filled with air, generally made of cast-iron, and heavily loaded, so as to sink when let down into the water by a rope, and furnished with thick glass to admit light. The operator is supported on cross benches near the bottom. As the bell is lowered to a greater depth, the pressure of the water becomes greater, and the air in consequence more and more compressed, so that the water ascends higher into it. To prevent the diver becoming thereby partly immersed in water, and to replace the air, which becomes vitiated by the respiration and the burning of the light sometimes employed, it is furnished with a valve and hose, through which fresh air is forced in, from a boat above, by a forcing pump. By this means it soon becomes again entirely filled with air, while the vitiated air is allowed to escape.

49. As an application of the condensation of air by the condensing air-pump, may be mentioned the *air-gun*, of which the essential part is a strong metallic receiver, into which atmospheric air is compressed to a considerable degree by a condensing syringe, which may be attached to it. Between this receiver and the barrel containing the ball, is a valve, which by pulling the trigger is struck open, thereby letting out a portion of the confined air, which propels the ball. In the ordinary air-gun the stock forms the receiver, and in the cane air-gun the receiver is formed out

of the hollow space between the barrel and the outer tube forming the cane.

50. Besides the condensing air-pump, other means are sometimes resorted to for the compression of gases. Thus, vapors are often obtained in a compressed state by the introduction of a volatile liquid into a confined space, and its conversion into vapors by heat. The *steam-boiler* is an illustration of this. The high-pressure *steam-engine* may be considered as a single-barrelled, double-acting air pump attached to it, the barrel being called the cylinder, but the piston of which, instead of condensing the gas by its motion, is itself moved by the elasticity of the gas, the vapor of water, already in the compressed state and let in alternately above and below the piston.

51. Another way of obtaining gases in a highly compressed state, is by generating them by chemical action in large quantities in a small space. Fire-arms may be considered as an application of this, the mixture employed in them for this purpose being the gunpowder. Many gases, such as carbonic acid, are most conveniently liquefied by the pressure produced by their own generation in an appropriate apparatus (see Chemistry under Carbonic acid).

Properties depending on Adhesion.

52. The repulsive action between the atoms of the same gas, which causes the property of Expansibility, we do not find to exist between the atoms of different gases. On the contrary, the atoms of one gas will allow the atoms of other gases to push themselves between them, and seem even to assist this action by an attractive force toward them (Adhesion). Thus, if two vessels, h and c *fig.* 13, separated by a partition p, be filled, the upper h with a light gas as hydrogen, and the lower c by a heavy gas as carbonic acid, and the partition between them be withdrawn, the hydrogen will not remain on top, but expand and spread downward through the carbonic acid; and in the same manner will the carbonic acid rise up, spreading through the hydrogen, till they both are evenly diffused through the whole space. This property is called *Diffusibility*. In virtue of this property one gas seems hardly to offer any resistance to the expansibility of another, and gases are therefore not capable of limiting each other, or of maintaining a distinct boundary between themselves (like oil and water among liquids).

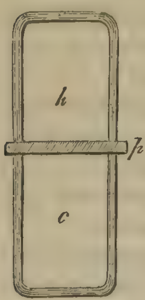


Fig. 13.

53. Diffusibility of gases suffers a peculiar modification, when they communicate with each other through extremely small openings,

as through a crack in a glass, or through a porous partition, as when formed of plaster of Paris, unglazed earthenware, common wood, particularly when cut across the grain, and animal membrane, as bladder, skin, &c. In all such cases the lighter gas will be found to pass through such into the heavier, faster than the heavier passes in the opposite direction into the lighter. Thus, if in *fig*. 13, the upper vessel *h* be filled with hydrogen, and the lower *c* with carbonic acid, and the partition *p* be a plate of plaster of Paris, it will be found that the hydrogen will pass faster into *c*, than the carbonic acid into *h*, and thus a partial vacuum is produced in the vessel *h*, occupied by the hydrogen, and a condensation in *c*. But after some time, when the gases become thoroughly diffused through each other, equilibrium is again restored on both sides of the partition. This may be illustrated by the *diffusion tube b fig*. 14, which is a glass tube open at the lower end and closed at the upper by a plug *a*, of perfectly dry plaster of Paris. If this be filled with hydrogen by displacement of the atmospheric air (see), so as to avoid wetting the plaster of Paris, and then quickly placed with its open end in a shallow vessel *d*, containing water, diffusion will take place through the Paris plaster, between the hydrogen in the tube and the atmospheric air outside, and the hydrogen passing out quicker than the atmospheric air passes in, a partial vacuum will be formed, by which the water will be forced up in the tube to *c* by the atmospheric pressure (see 59), several inches above the level outside. But after some time it again falls to its former level. This kind of diffusion, particularly when taking place through animal or vegetable membranes, is often called by the name of Endosmosis and Exosmosis. The velocities with which different gases diffuse themselves, have been found to be, under otherwise similar circumstances, inversely proportional to the square roots of their densities or specific gravities.

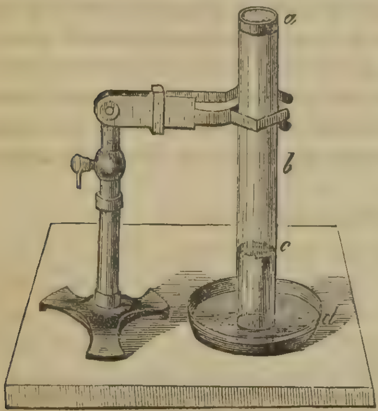


Fig. 14.

54. The adhesion of gases toward Solids is quite considerable, so that in many cases it causes them to be condensed in greater or less quantities on their surface. Thus, it is found that ordinary glass, even when perfectly dry to the touch, always contains a thin film of vapor of water condensed on its surface. This becomes more perceptible when its surface

is increased by pulverizing it, when the quantity of vapor condensed by it may be so great as to amount to more than ½ per cent. of its weight. The same is the case with most other pulverulent or porous bodies, such as clay, and particularly animal and vegetable substances, as paper, wood, hair, membranes. Such water is called *hygroscopic* moisture and is found to vary in quantity according to the state of humidity of the atmosphere (177), and interferes materially in many experiments with the accurate determination of their weight. Recently ignited charcoal will absorb many times its own volume of different gases, such as oxygen, and particularly sulphuretted hydrogen and other similar gases or vapors, which are the cause of offensive odors. On this depends its preserving and deodorizing properties. The most extraordinary instance of such condensation of gases is presented by platinum towards hydrogen and oxygen, when in porous and finely divided states, in which it is called platinum sponge and platinum black, the latter of which has been found to absorb more than 250 times its own volume of oxygen. By this condensation a subsequent chemical action is often induced. Thus, oxygen when absorbed by charcoal combines after some time with it, forming carbonic acid in its pores; and hydrogen and oxygen when absorbed together by platinum sponge unite to form vapor of water, so that platinum sponge when held before a jet of hydrogen, where it mixes with the oxygen of the atmosphere, will become heated by the union of the two gases, and ignite the jet of hydrogen. On this depends the Platinum Igniter, (*fig.* 15), which is an apparatus for obtaining fire, consisting of a self-regulating generator of hydrogen (see), which by turning up the box *h*, opens a stop-cock and causes the hydrogen to issue from the jet *e*, on the platinum sponge h_1 and thereby to become ignited.

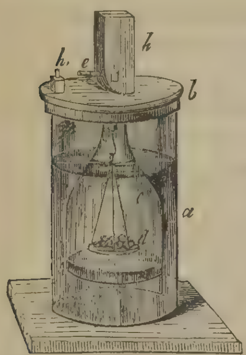


Fig. 15.

55. Towards Liquids also, a positive attraction or adhesion is very manifest, by which the atoms of gases are drawn in between the atoms of liquids, which constitutes what is called *absorption* or *solution* of gases in liquids. Thus all the atmospheric gases dissolve in water in small quantities, and on the oxygen thus dissolved (about $\frac{1}{100}$ vol. in 1 vol. of the water), depend all gill-breathing animals for their respiration. Some gases dissolve in considerable quantities in water, as carbonic acid (1 vol), and sulphurous acid (50 vols). It is, however, often difficult to draw the line between mere solution or absorption and chemical combination. Thus, chlorohydric acid dissolves in water to the amount of 418 vols.,

and ammoniacal gas to the amount of 500 vols.; but in these cases a chemical combination with the water takes place at the same time.

56. When a gas is dissolved in a liquid, and the free surface of this solution be exposed to, or brought in contact with another gas, or be separated by a porous partition from it or from a solution of it in a liquid, diffusion will, in all such cases, take place between them. It is by such diffusion that by respiration an exchange takes place, through the membrane of the lung, between the oxygen of the air and the carbonic acid dissolved in the blood: and that in gill-breathing animals an exchange is effected, through the membrane of the gill, between the oxygen dissolved in the water and the carbonic acid dissolved in the blood. This is also the cause why, when gases are separated by liquids in which they are more or less soluble, an exchange of them always takes place by diffusion through the liquid. This is not only the case when a gas is confined by a very thin film of liquid, for instance, when enclosed in a soap-bubble; but even when gases are kept in jars, placed with their mouth in water, it is found, that in the course of time more or less of an exchange takes place through the water with the atmospheric air outside. Thus, if the gas be hydrogen, in the course of some weeks, some of it will have escaped through the water, while a perceptible quantity of atmospheric air will have found its way through the water into the hydrogen. As gases are utterly insoluble in mercury, this liquid is often employed for confining them more perfectly, and answers well when the surfaces of the glass and the mercury are perfectly clean. But if a film of dust cover the glass or be on top of the mercury, when immersing the mouth of the vessel into it, so as to prevent perfect contact between the glass and the mercury, diffusion will take place through this film.

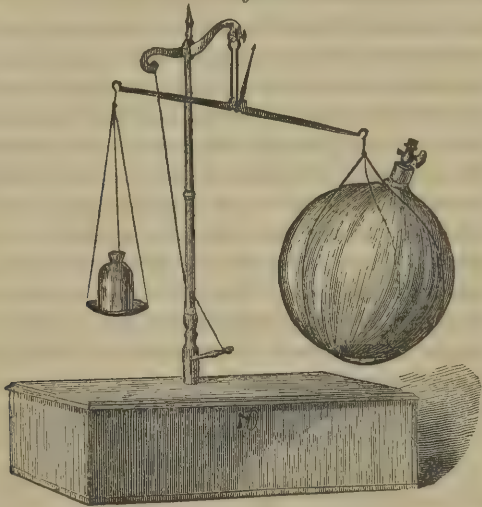
Properties depending on Gravity.

57. Gases are subject to the action of gravity, and they are, therefore, like all other ponderable matter, attracted by the earth towards its centre, which constitutes their *weight*. To prove this, attach a spherical receiver furnished with a stop-cock, to an exhausting air-pump, and having removed the air, counterpoise it on a balance, see *fig.* 16, so as to produce equilibrium. Allow then the atmospheric air to fill the receiver by opening the stop-cock. It will be found that the receiver now weighs more. This gain is due to the weight of the gases which now fill the receiver. By forcing more air into the receiver by the condensing air-pump, we shall find that its weight is still further increased. By accurate experiments it has been found, that 100 cubic inches of atmospheric air, freed from its

carbonic acid and vapor of water, at 30 inches barometric pressure and 60° Fahrenheit, weigh exactly 30.82926 grains, (or at 32° Fah. 32.58685 grs).

58. Different gases have different weights for the same volume. Thus, 100 cubic inches of oxygen weigh 34.19 grains, of hydrogen 2.14 grains, of carbonic acid 47.14 grains. By the *density* or *specific gravity* of a gas we understand the number which expresses, how many times a gas is heavier

Fig. 16.



than the same volume of atmospheric air, which is, therefore, the standard of comparison and its specific gravity = 1. To obtain the specific gravity of a gas, we first fill a suitable spherical glass receiver, as above, with atmospheric air, freed from its carbonic acid and vapor of water by passing it through a tube filled with unslacked lime, and ascertain accurately the weight of the atmospheric air in it. We then again exhaust the atmospheric air and fill it with the gas (see), at the same temperature and at the same pressure, and ascertain its weight. The weight of the gas divided by the weight of the atmospheric air will then give us its specific gravity. The following are the specific gravities of some of the different gases;

Atmospheric air.......	1.0000	Nitrogen...............	0.97137
Oxygen.................	1.1056	Carbonic acid.........	1.529
Hydrogen..............	0.06926	Vapor of Water......	0.622

To avoid fractions the specific gravity of atmospheric air is often called 1000 instead of 1, that of oxygen then becomes 1105, hydrogen 69, &c.

59. As gases possess weight, it follows that the surface of the earth

must sustain a considerable pressure from the weight of the surrounding atmosphere resting on it. To prove this, place an open glass tube with one of its extremities in water, see *fig.* 17, and remove the air which it contains by suction with the mouth, or by an air-pump attached to the other end *a*. We shall find that as the air is removed, the pressure of the atmosphere on the water outside the tube will force it up into it. On re-admitting the air into the tube the water will again fall to its former level. For the same purpose expel the air from a tube closed at one end, by filling it with water; invert it, keeping the finger on the open end to prevent the water from escaping, and introduce this end into a vessel with water. On removing the finger the water does not run down, but the tube remains filled with the water to the top, caused by the pressure of the atmosphere on the water outside of it. As soon as the air be again in any way admitted into the tube, the water will fall as before. If we perform the same experiments with mercury instead of water, and use a tube longer than 30 inches, we shall find, that on removing the air from the inside, the pressure of the atmosphere on the outside is not capable of forcing the mercury up to the top of the tube; or of retaining it there, if closed at one end and filled and inverted as before, but only at the perpendicular height

Fig. 17.

Fig. 18.

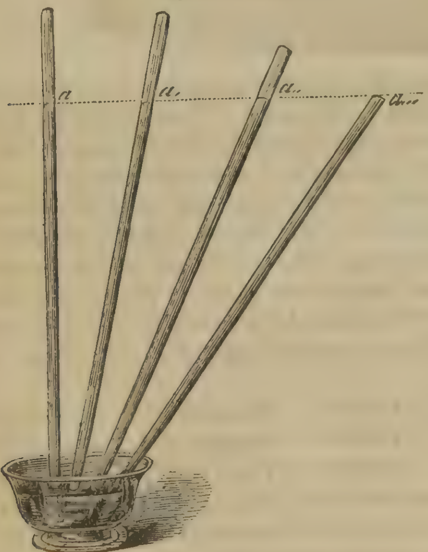
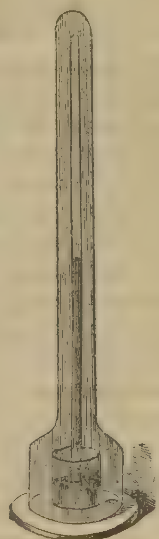


Fig. 19.



of about 30 inches above the level of the mercury outside, see *a fig.* 18, and at which level, therefore, the mercury will remain, whatever inclination we give the tube, as represented at a_1 a_{11} a_{111} *fig.* 18. That it still is the pressure of the atmospheric air outside, which sustains the mercury in the tube, may be further proved by placing the whole under an appropriate pneumatic receiver, see *fig.* 19, and exhausting the air, when the mercury in the tube will be found to fall as the air is withdrawn from outside of it; and if it were possible to remove the air perfectly, the level inside and outside would be the same in this case, as when the atmosphere is both inside and outside. As water is 13.6 times lighter than mercury, the atmospheric pressure is capable of forcing it up to a height 13.6 times greater than that of the mercury, or to about 34 feet.

60. The pressure of the atmosphere was discovered by the circumstance, that some Italian pump-makers had in vain endeavored to raise water by a suction-pump to a greater height than 34 feet, and applied to Galileo for the reason. Previously, the cause of water rising in a tube under such circumstances had been ascribed to what was called the abhorrence of nature to a vacuum, by which nature always endeavored to fill it up. Galileo referred the subject to his pupil Torricelli, who at once suspected the real cause to be the pressure of the atmosphere consequent to its weight, and to convince himself of the correctness of the above facts in regard to water, performed (about 1643 A. D.), the experiment of filling a tube longer than 30 inches with mercury and inverting it in a cup of mercury. Such apparatus is yet called after him a *Torricellian tube.* The real proof, however, of the mercury in the tube being supported by pressure from the atmosphere, was obtained by Pascal having it carried up a high mountain, by which the air underneath became incapable of pressing on the mercury, and this therefore gradually fell as the height became greater.

61. The Torricellian tube furnishes us with the means of estimating the pressure of the atmosphere on the surface of the earth, which for the greater part, though not entirely, depends on the weight of the atmosphere. For this purpose it is only necessary to measure accurately the perpendicular height of the mercurial column,—this being the only part of it which is sustained by the atmosphere, the rest, when inclined being supported by the sides of the tube. This height will be found, as before stated, to be about 30 inches. The pressure of the atmosphere on the surface of the earth is therefore equal to a layer of mercury all over it 30 inches in height. We therefore only need calculate the weight of a column of this height and of a certain base, in order to obtain the pressure of the atmosphere on an area equal to this base. We thus find, that a column of mercury, which has the height of 30 inches and rests on a base

of one square inch, contains 30 cubic inches of mercury and will weigh $14\frac{3}{4}$ pounds, which is therefore the amount of the pressure of the atmosphere on every square inch of surface. The mercurial column in the Torricellian tube does not, however, always remain the same, but is found to vary in the same place at different times about 3 inches. The pressure of the atmosphere is, consequently, not uniform, but varies to the amount of $1\frac{1}{2}$ pound on the square inch. In most calculations it is considered as being equal to 15 pounds to the square inch, and in the estimation of pressures this is considered as a unit under the name of one Atmosphere, so that for instance a pressure of 3 atmospheres means a pressure of 45 pounds to the square inch.

62. If the Torricellian tube be prepared with care so as to expel all the atmospheric air and moisture, which adhere to the tube, and which is done by boiling the mercury in it before inversion, it will easily be seen that the vacuum produced above the mercury by the subsequent inversion, must be entirely free from any of the gases of the atmosphere. Hence, this space is called the *Torricellian vacuum*, in contradistinction to the vacuum which may be produced by an air-pump. At the temperature between 60° and 80° Fah., it begins, however, to contain a perceptible trace of vapor of mercury.

THE BAROMETER.

63. As the pressure of the atmosphere varies, it becomes important to estimate at any time its amount with accuracy. Instruments constructed for this purpose are called *Barometers*, from βαρος (baros) a Greek word signifying weight, and μετρον (metron) measure, meaning literally measurer of the weight of the air (see 90). In the ordinary form it consists of a carefully prepared Torricellian tube (60), inverted in a very small cup or cistern containing mercury, and furnished with an accurate scale, by which we are able to read off at any time the height of the mercurial column above the level of the mercury in the cup.* This is called the *cup* or *cistern barometer*, see *figs.* 20 and 32. In order to fix the tube to

* In the making of accurate barometers certain precautions are necessary in the filling of the tube. By keeping, more or less dust always finds its way into open tubes. Barometer tubes should therefore, if practicable, be sealed at both extremities immediately after they have been drawn at the glasshouse, and be kept in this state till ready for use, when one end is cut off. Where this cannot be done, it may become necessary to wipe them clean inside by a thin copper wire, wrapped over with dry thread. Should it be found indispensable to clean them with water, this is best removed by rinsing with strong

the cup, the latter may be furnished with a cover of wood, cut across the grain, by which it is sufficiently porous to let the atmospheric pressure through it, without allowing the mercury to be spilled out of the cup, and through which cover the tube may then be fixed (*fig.* 32), or the whole cistern may be made of wood, as in *fig.* 20, the top being in one piece with it, and the bottom screwed on before inverting it. Instead of having a cup attached to the tube, the tube may be bent at the lower extremity so as to have the open end turned upward, see *fig.* 21, in which case this open end acts as the cup, and it is then called a plain *syphon barometer*, or if the open end be blown into a bulb or cup, as in *fig.* 22, it is called a *syphon cup-barometer*. The whole apparatus is then fastened to a board, *figs.* 21 and 22, or enclosed in a case of wood or brass, *figs.* 28 and 32, on which the scale is fixed. The whole scale is, however, rarely affixed to the barometer, but only so much of its upper portion, as is necessary for the intended use; on ordinary baro-

Fig. 20.

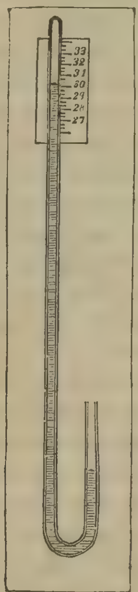


Fig. 21.

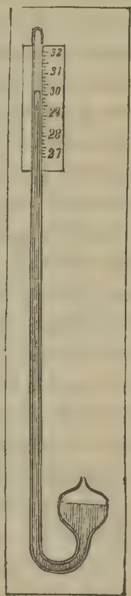


Fig. 22.

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alcohol, after which the tube is dried by heating it on the outside at a short distance from one of the open ends, and drawing dry air through it by suction from the other end. As it is almost impossible to remove any moisture in the tube after it has been sealed at one end, the greatest care should be taken to avoid introducing any by the breath, or by the flame of the blowpipe lamp. The sealing should therefore be done by drawing the tube out at such a distance from the end as to prevent this. Before filling, both the tube and the mercury should be strongly heated, and in some cases it may even be necessary to heat the mercury to boiling after its introduction into the tube. The mercury employed should be purified. This is generally done by forcing it through skin and by digesting it in a lukewarm place with muriatic or diluted sulphuric acid. For standard barometers it should be distilled. Distilled mercury is apt to become covered with a black film at the open end, but this is prevented by subsequent digestion with strong muriatic acid and thorough washing with water to remove the acid. Syphon barometers are filled with the mercury as high up as practicable before bending them, after which the filling is completed through the open end by suitable manipulations. Barometer tubes contracted at any point to capillary dimensions must be filled in the same manner, as thermometer bulbs (35).

meters seldom more than 4 or 5 inches. In all cases, whether cup or syphon barometer, the height of the mercurial column is measured by the *perpendicular* distance from the level of the mercury in the open part to the top of the mercury in the closed end of the tube.

64. All barometers have the inconvenience, that when the mercury in the upper closed end of the tube rises or falls by a variation in the pressure of the atmosphere, a portion of the mercury is either abstracted from, or added to the mercury in the open part, by which the level of this latter, which forms the beginning of the scale, is altered. In the cup-barometer this error may be diminished sufficiently for ordinary purposes, by making the upper part of the cup, where the mercury rises and falls, see *g fig.* 20, of a considerably larger diameter than that of the tube at the upper level of the mercury. Thus, if the diameter of the cup be 10 times greater than that of the tube, their relative contents, which are proportional to the squares of their diameters, will be as 100 is to 1, and therefore a fall of one inch in the tube will only raise the level in the cup $\frac{1}{100}$ of an inch. Where, however, the utmost accuracy is required, it becomes necessary to avoid this error altogether, which is done, either by making the scale movable and adjusting its lower end to the level of the mercury in the cup, or by furnishing the cup with a movable bottom of skin, which may be raised by a screw, see *h fig.* 32, by which the mercury may always be adjusted to the same level. This level is sometimes indicated by a float in the mercury, the stem of which passes through the cover, but more frequently, and with greater reliance, by a point of ivory projecting down from the cover of the cup, see *fig.* 32 at *p*, the cover being made of wood cut across the grain, so as to allow the air free ingress through its pores, and the sides of the cistern of glass, so that the point is visible through it. To adjust the level of the mercury in such cistern before making an observation, the mercury in it is raised by the screw at the bottom, till the ivory point, by dipping into the mercury, forms a small cavity in its surface; it is then lowered till this cavity just disappears.

65. In the plain syphon barometer, *fig.* 23, the above inconvenience may be avoided by having the bore of the two limbs of the tube of exactly the same diameter or calibre. It will then be seen, that when the mercury in the closed end rises, for instance, ½ inch, it must fall exactly the same amount, or ½ inch, in the open end; and thus the difference between the two levels will be one inch. In the same manner all changes of the barometer will always be double that indicated in the closed end, so that if the barometer be correct at 30 inches, it is only necessary to double the value of the other divisions of the scale, that is, half an inch above is marked 31 inches, and half an inch below, 29 inches, and so on. As,

however, it is extremely difficult to obtain the bore of the two limbs of exactly the same diameter, any uncertainty arising from a variation in their calibre, may be avoided by drawing an arbitrary horizontal line, see *a fig.* 24, between the upper and lower level of the mercury, and furnishing each limb with a separate scale, which two scales, *s* and *s*, measure, the one the distance from this horizontal line to the level of the mercury *above* it in the closed limb, the other the distance from this same line to the level of the mercury *below* it in the open limb, which two measures added together will give the true height of the whole column.

Fig. 23.

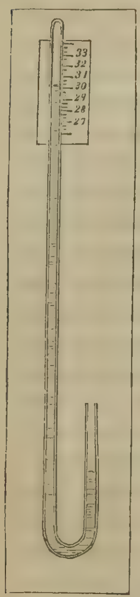
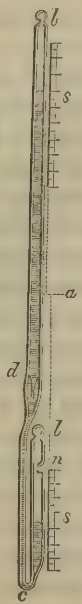


Fig. 24.



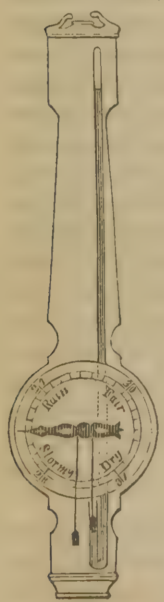
66. A great object in a good barometer is to be able to measure with accuracy *small* changes in the pressure of the atmosphere. But on account of the high specific gravity of the mercury, being nearly 11000 times heavier than atmospheric air, these changes are only indicated by extremely small changes in the mercurial column. To remedy this inconvenience, so as to increase the actual motion or *show* of the barometer, different means have been proposed. As the first of these, may be mentioned the substitution of a specifically lighter liquid instead of the mercury. But in the same proportion as the specific gravity of the liquid becomes less, the barometer becomes longer and less portable. In the Royal Society of London, there is a barometer which was constructed by Daniell with Water, instead of mercury, the column of which was therefore 34 ft. high, and varied by the changes in the atmosphere about 3 ft., so as to be almost constantly in a state of motion. But besides the above named inconvenience from its size, which would not be an objection for stationary observatories, all such liquids are liable, if volatile, as water, to evaporate from the open end, and for the same reason to form a vapor in the vacuum at the closed end, which varies with the temperature, and of which an account must be kept; or, if not volatile, as oil, to change by contact with the air or the sides of the tube.

67. The mercury being thus the only liquid, which can be employed with advantage in the construction of barometers, it has been attempted to produce the same effect of increasing its show by attaching certain mechanical contrivances to the mercurial barometer.

68. Thus, in the Diagonal or Inclined Plane Barometer, the upper closed portion of the tube, in which the mercury rises and falls, instead of being perpendicular, is inclined so as to form a considerable angle with the perpendicular. As the changes of the barometer are measured by the perpendicular height, it is evident, that the mercury in order to arrive at the same perpendicular height, must travel through a longer distance along the inclined part of the tube, and thus the motion of the barometer is increased in the proportion of the hypothenuse of a right angled triangle, to its perpendicular side, or as the diagonal of a rectangle, to the same. But as only the perpendicular part of the mercury on the inclined portion is supported by the atmospheric pressure, the rest being supported by the inclination of the tube, the friction of the mercury against the sides of the tube is much greater, and will prevent small changes in the pressure of the atmosphere from moving the mercury until they become larger, when they will appear in the above increased proportion. Thus the small changes, which are the most difficult to observe, are not indicated at all in this barometer.

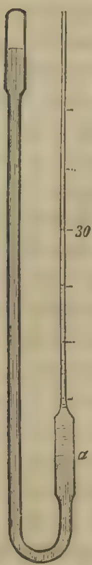
69. Another barometer constructed with a view to the same advantage, is the Wheel Barometer (Hooke's), see *fig.* 25, which consists of a syphon barometer, having in the mercury of its open limb, an iron or glass float, to which is attached a string, that passes over a small wheel or pulley and is kept extended by a small weight attached to the other end. The axis of the wheel is furnished with an index, which traverses a circular scale. It will easily be seen that when the level of the mercury changes in the open end, the float will follow it and by the string move the wheel, and its index will thus pass over the circular scale, the length of which must be in proportion to the length of the index. The graduations on the scale are made to indicate the corresponding rise and fall of the mercurial column in inches. Though as regards very small changes, this barometer is liable to the same objections as the former, that these are not indicated on account of the friction of the weight and the pulley, and the rigidity of the cord; still for ordinary meteorological purposes it forms both a cheap and an handsome instrument, and is therefore often met with in parlors and studies, as a 'weather glass.' As regards accuracy they are, however, often made very indifferently, and in such cases are not reliable for barometrical observations.

Fig. 25.



70. A third barometer of this kind is Huyghen's Double-Barometer, *fig.* 26. It is a syphon-barometer, the two ends of which are widened where the mercury rises and falls. The open end terminates in a long open capillary tube. The mercury of the barometer fills half of the wide portion of the open end to a, but the other half of it and part of the capillary tube, are filled with colored spirits of wine. It is evident, that any change in the level of the mercury by the pressure of the atmosphere, will cause a certain quantity of the spirits to be forced into, or withdrawn from, the capillary tube, and thus produce a change in the level of the spirits in the latter so much greater, as its relative capacity is less, which change may be magnified to any desired extent by diminishing the diameter of the capillary tube. It has, however, been found that the spirits is apt, by its greater adhesion to the glass, to work its way between the mercury and the tube into the vacuum at the closed end, and thus render it liable to get out of order.

Fig. 26.

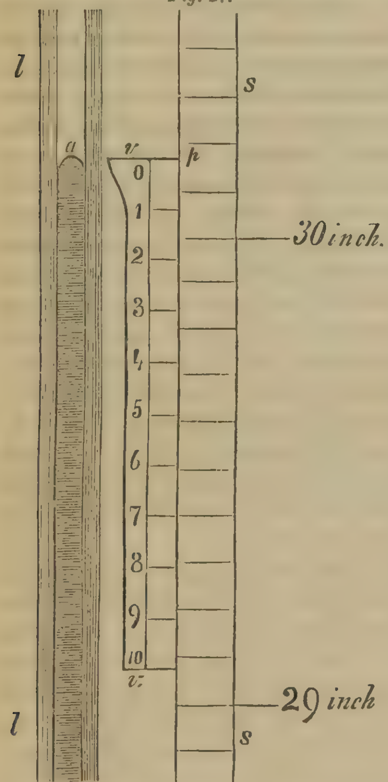


71. All these contrivances for increasing the actual motion or show of the mercurial barometer have therefore been abandoned for very accurate scientific purposes, and, instead of them, increased power and accuracy of observing and measuring have been substituted. For this purpose the scale of the barometer is furnished with a *sight*, or horizontal line, which the observer may slide along the tube until, by looking over it, he may bring the top of the mercury on the same horizontal level with it, and thus transfer the level of the mercury to the exact point on the scale, which corresponds to it. On account of the difficulty to the eye to count small divisions, the scale is rarely divided into smaller parts than tenths of an inch, or at most, the tenths are again divided into halves, or $\frac{5}{100}$ths. As on this account the point transferred will rarely coincide with a division of the scale, a *vernier* is attached to the sight, in order to measure the exact distance of the point from the nearest division of the scale.

72. The Vernier see v v_1 *fig.* 27, is a short scale sliding on the main scale, the use of which therefore is, when a point does not coincide with a division of the main scale, to measure its distance from this division. To obtain this distance, one of the extremities of the vernier, either its zero or its highest number, is placed at the point in question, and the vernier then gives its distance from the last counted division on the main scale by a fraction, which has for its numerator the number of that division of the vernier, which coincides with a division on the main scale, and for its denominator the whole number of divisions of the vernier, multiplied by the denomina-

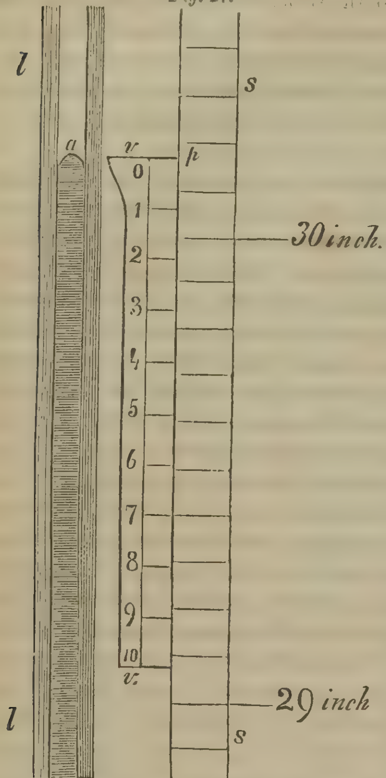
tor of the value of the smallest divisions of the main scale. The vernier is always fixed in such manner to the sight, that when the latter is brought on a level with the top of the mercury, the nearest extremity of the vernier (either its zero or its highest number) is made to indicate the exact point on the main scale, which corresponds to the top of the mercury. If this then coincide exactly with a division on the main scale, this division is counted and the vernier is not used. But if the extremity of the vernier do not coincide with a division on the main scale, we first count or read off the height to the nearest lower division on the main scale, and add to this the distance from it to the extremity of the vernier, which distance is obtained, as stated before, by looking along the vernier, to find the division on it, which coincides with a division on the main scale. Thus, let *l l fig.* 27 represent a section of a portion of the tube of a mercurial barometer, with its scale *s s* divided into inches and tenths of inches, *a* the top of the mercury in the closed limb, and *v p* the sight transferring its level to the scale *s s* at *p*, being also the zero-extremity of the vernier $v\ v_1$. It is evident that the nearest lower division on the main scale is 30.1 inch, and the height to the point *p*, therefore, 30.1 inch + the distance from 30.1 to *p*. This distance is then given by the vernier to be $\frac{7}{100}$ of an inch, 7 being the number of the division on the vernier, which coincides with a division on the main scale, taking this number as the numerator, while the denominator 100 is obtained by taking the whole number of divisions of the vernier, 10, and multiplying it by 10, the number which is the denominator of the value of the smallest division of the main scale ($\frac{1}{10}$th of an inch.) The distance from 30.1 inch to *p* thus being $\frac{7}{100}$ = 0.07 inch, the whole height of the mercurial column must of course be 30.1+0.07=30.17 inch; so that hav-

Fig. 27.



ing read off on the main scale the number of inches and tenths, we only have to add the number on the vernier at the coincidence as hundredths.

Fig. 27.



73. To understand this, it must be stated, that the vernier always subdivides the smallest divisions of the main scale in as many parts as it has itself divisions. This is effected by taking the number, into which it is to subdivide the smallest divisions of the main scale, + or — 1, as its length, and dividing this length into the former number of equal parts. Thus in *fig.* 27 the smallest divisions of the main scale are tenths of inches, which the vernier again subdivides into tenths and thereby gives hundredths of inches. It is therefore constructed by taking eleven (10+1) divisions of the main scale ($\frac{11}{10}$ths inch) as its own length, and dividing this into ten equal parts. We thus have that ten divisions of the vernier are equal to eleven of the scale, or $10\ v = 11\ s$, therefore, $1\ v = 1\frac{1}{10}s$, or that each division of the vernier is $\frac{1}{10}$th larger than the smallest division of the main scale, and as this is itself one-tenth inch, each division of the vernier must be *one hundredth of an inch* longer than the smallest division of the scale. If therefore (see *fig.* 27) the 7th division of the vernier coincides with 29.4 inch on the main scale, the 6th division of the vernier must be *one hundredth of an inch* above 29.5 (the next higher division on the main scale); the 5th be *two hundredths* above 29.6; the 4th be *three hundredths* above 29.7; the 3d be *four hundredths* above 29.8; the 2d be *five hundredths* above 29.9; the 1st be *six hundredths* above 30.0; and 0 or the zero point be *seven hundredths* of an inch (7 being the number at the coincidence) above 30.1 inch on the main scale. The distance from 30.1 inch to the point p is thus indicated by the vernier to be 0.07 inch, as stated above, and the whole height of the mercurial column 30.17 inches. It is

also evident from the same *fig.* 27, that the vernier may equally well be fixed in such manner, that its lower extremity v_1 (or 10 of the vernier) transfers the top of the mercury to the scale, as the same number at the coincidence 7 will indicate the distance of its lower extremity from 29.0 inch on the main scale, and this point therefore be 29.07 inches; only that in this case in looking from the last counted division on the scale along the vernier, its numbers appear reversed in order, beginning with the highest.

74. When the vernier (so named after its inventor) is so constructed, that its ten divisions are equal to nine of the main scale, it is often called a *Nonius*, meaning the ninth. Each division of this vernier is $\frac{1}{10}$th shorter than the smallest division of the main scale. The principle and the mode of reading it off are exactly the same as those of the last described vernier, (*fig.* 27), only that when both are fixed in the same manner, their numbers always run in the reversed order of each other. Two similar verniers constructed by making their 20 divisions equal to 19 of the main scale, are seen in *fig.* 33, which represents the upper portion of the Levelling Barometer, *fig.* 32, and will be further explained under it (81).

75. *Effect of Capillarity.* A source of inaccuracy in obtaining the true height of the mercurial column is caused by the capillary action of the tube on the mercury, by which the latter is prevented from rising to its proper height, and thus instead of a higher and level surface, presents one that is lower and convex. This error is, however, constant for the same barometer, and may be avoided altogether by fixing the scale, as is usual with all excepting standard barometers, not by the actual height of the mercurial column, but by comparison with a standard. Should this not have been done, this error may be estimated from the diamater of the bore of the tube, as given by the following table.

Table of Corrections for Capillarity.

Diameter of Tube.	Correction for Capillarity.		Diameter of Tube.	Correction for Capillarity.	
	Mercury boiled.	Mercury not boiled.		Mercury boiled.	Mercury not boiled.
Inch.	Inch.	Inch.	Inch.	Inch.	Inch.
0.60	0.002	0.004	0.30	0.014	0.028
0.50	0.003	0.007	0.25	0.020	0.040
0.45	0.005	0.010	0.20	0.029	0.060
0.40	0.007	0.014	0.15	0.044	0.088
0.35	0.010	0.020	0.10	0.070	0.142

This correction is always to be *added* to the observed height. The first column is to be used, where all the air and vapor adhering to the tube (54)

have been expelled by the boiling of the mercury (62 and 63); the second column where this is not the case, and is also applied to the level in the *open* part of syphon barometers.

76. *Effect of Friction and Adhesion.* Another source of error, more difficult to guard against, is caused by the friction of the mercury against, and its adhesion to the tube, by which, instead of moving freely up and down by any change in the pressure of the atmosphere, it remains attached to the sides, so that when it is falling, it at first exhibits a less convex and afterwards even a concave surface, and may at last be prevented from falling any further by the mercury on the sides not following it; when, on the contrary, it is rising, it exhibits a more convex surface than it ought, and is also prevented by the adhesion of the mercury to the sides, from rising to its proper height. To avoid this error the mercury should always, before taking an observation, be put in motion by gently tapping with the finger on the outside of the tube; or, if the barometer be suspended so as to swing freely, a moderate motion may be imparted to the whole instrument.

77. *Effects of Temperature.* As mercury expands by heat and thus diminishes its density or specific gravity, it will require a proportionally greater height to counterbalance the same pressure, and it therefore becomes necessary to refer all observations to a standard temperature. This standard temperature is generally assumed at 32° Fahrenheit, or 0° Centigrade. The temperature of the mercury must, therefore, be ascertained, at the same time that its height is observed, by a separate thermometer, with which all accurate barometers are furnished, see *l fig.* 28 and *g fig.* 32; and if the mercury be not of this standard temperature, the *observed* height must be reduced to the *true* height, that is, the height it would have, if it had the standard temperature, by applying a correction to it. As mercury expands for every degree Fahrenheit 0.0001001 of its volume, we obtain this correction by multiplying this fraction, first, by the number of degrees above or below 32°, and then by the observed height, which correction is deducted if the temperature be *above* 32°, and added if the temperature be *below* 32°, or calling the observed temperature t, and the observed height h_1 the correction for temperatures above 32° will be $= - 0.0001001\,(t - 32°)\,h_1$, and for temperatures below 32° $= + 0.0001001\,(32° - t)\,h_1$. But the scale also expands by heat and contracts by cold and is therefore only correct at a certain normal or standard temperature, which for English measures is 62°. Above this temperature we therefore measure the height by too long a scale and obtain the height too small, and we must therefore add to the observed height the expansion of the scale. Below this temperature we

measure it with too short a scale and obtain the height too large, and we must therefore deduct from the observed height this contraction. The expansion of brass being for every degree Fahrenheit 0.0000104, we obtain this correction for a scale entirely of brass, and extending the whole length from the lower to the upper level of the barometer, by multiplying this expansion, for one degree, first, by the number of degrees above or below 62°, and then by the observed height, which correction is to be added, if the temperature be above 62°, and deducted if below, being therefore for temperatures above $62° = +0.0000104\ (t—62°)h_1$, and for temperatures below $62° = —\ 0.0000104\ (62°—t.)h_1$. These two corrections for the expansion of the mercury and the scale will be found to counteract each other at 29°, which is therefore the only temperature at which no correction is necessary.

If the barometer be French, and therefore have a scale of millimeters and a Centigrade thermometer, we have, that the expansion of the mercury for each degree Centigrade is 0.0001802, and for brass 0.0000188. But as the standard temperature for French measures is 0° Centigrade, the same as for the mercury, we may deduct the expansion of the brass from that of the mercury, leaving only one correction for both, being for each degree Centigrade 0.0001614, which fraction we multiply, first, by the number of Centigrade degrees, and then by the observed height, being for temperatures above $0° = —\ (0.0001614 \times t)\ h_1$ and for temperatures below $0° = +\ (0.0001614 \times t)\ h_1$.*

Where many such corrections are to be made, they are most conveniently performed by the aid of a table, for which purpose see Table II, at the end of Pneumatics page . For a more complete table the reader is referred to Meteorological Tables prepared by Guyot and published by the Smithsonian Institution.

If the scale be engraved on the glass tube, and therefore of glass, the expansion of glass must be substituted in the above formulas for that of brass, being for 1° Fahrenheit 0.0000045 and for 1° Centigrade 0.0000081. Where the scale is a brass plate fastened on wood, no accurate correction

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* The above expansions ought properly to be referred to the true height (32°) instead of the observed height. The accurate and complete formula for this *correction* for temperature is— $\frac{m\ (t—T)—l\ (t—\vartheta)}{1+m\ (t—T)}\ h_1$; in which h_1 = the observed height; m = cubical expansion of the mercury for 1 degree, l = the linear expansion of the material of the scale for 1 degree; t = the observed temperature of the mercury; T = the standard temperature, to which the observed mercurial height is to be reduced; ϑ the normal or standard temperature, to which the scale must be reduced in order to be correct, and which for English measures of brass is at 62°.

can be made for the temperature. As wood is also influenced by moisture, and its expansion by heat very small (about one-half that of glass), it is common to apply in such cases only the correction for the expansion of the mercury, which will be found in Table I, at the end of Pneumatics. By deducting from these corrections $\frac{1}{40}$th of their amount for *wood*, and $\frac{1}{20}$th for *glass*, they will be sufficiently accurate for all purposes.

We will now describe a few mercurial barometers as intended for special purposes, and point out their peculiarities.

Fig. 28.

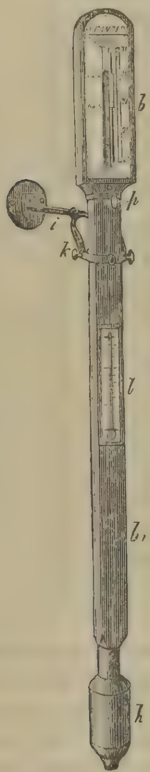
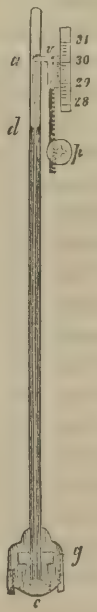


Fig. 29.

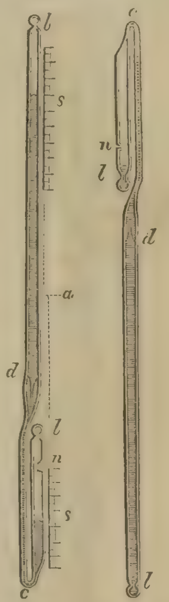


78. On board vessels a barometer is required of at least moderate accuracy, but of simple construction, so as not to be liable to get out of order. It is also desirable to avoid metallic scales or cases, as they are liable to rust by the moist air and salt water. *Fig.* 29 represents the inner arrangement of such a Marine Barometer, and *fig.* 28 shows it fixed in its case and suspended. The cistern is made of wood, in one piece with the cover, into which the tube is cemented. The bottom, being in part of skin, see *c fig.* 29, is screwed on before inverting it. The cistern at *g*, where the mercury rises and falls, is widened, to diminish the error arising from a change in its level (64.) The greater portion of the tube, as far as *d*, is contracted to a very small diameter to avoid violent oscillations. The tube with the cistern is introduced into the case by unscrewing the lower part of *h fig.* 28, which is of brass. The rest of the case *b* b_1 is of wood, widening at the top into a box with glass front and containing the scale. The latter is of ivory and is divided into tenths of inches, with a vernier *v fig.* 29, also of ivory and worked by a rack and pinion, the head of which *p fig.* 28, is on the outside. The inches and tenths of inches are read off on the main scale, and the number on the vernier at the coincidence added as hundredths, as explained in 72 by *fig.* 27. It is suspended from a

bracket i by a universal joint k, so as to remain perpendicular during the motions of the ship.

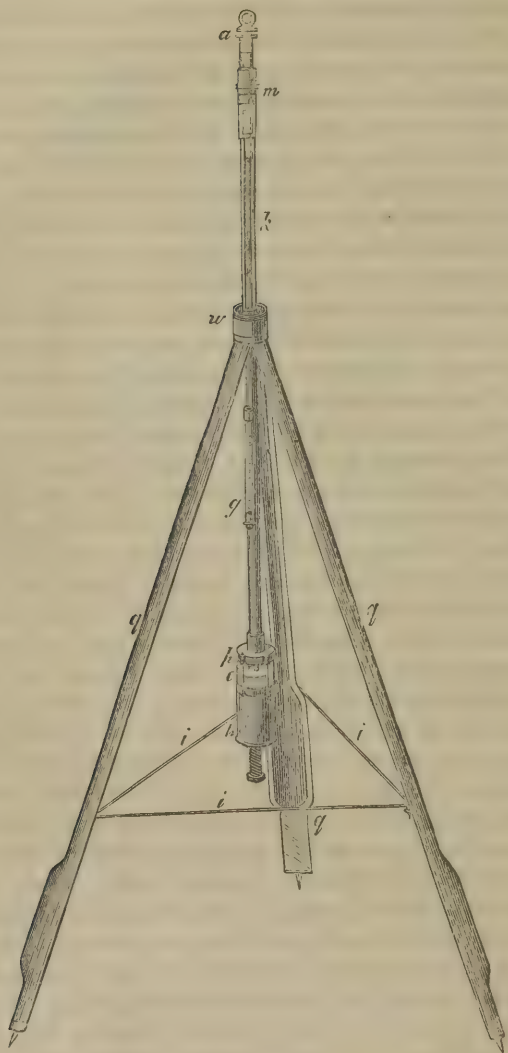
79. For accurate barometric observations through long and rough journeys over mountainous regions, particularly with a view to estimate the relative elevations of the country, Gay Lussac's Portable Syphon Barometer is generally employed. It consists of a plain syphon barometer, enclosed in a brass tube with longitudinal openings for viewing the mercury, on the edges of which the scales are engraved, each limb being furnished with a separate scale, see s and s *fig.* 30, to measure the distance from an arbitrary horizontal line a between them, which two measures added together, give the height of the mercurial column, as explained in 65. As this and other barometers are frequently imported from France, its scales are generally in French Millimeters.* Each scale has its separate sight, consisting of a ring moving on the outside of the brass tube, with a vernier attached giving tenths of millimetres. The glass tube, as represented in *fig.* 30, has the lower extremity of the long limb and the bend c contracted to a capillary diameter, so that any violent motion of the mercury is checked, and by inverting it, in which position transportable barometers are always carried, the mercury remains in the bend c as represented in *fig.* 31, and to prevent the mercury in the rest of the short limb from escaping from it, this is closed at its extremity, which receives the mercury, but a small capillary orifice n, with the edges turned inward, is left at a short distance from it to admit the air. Near the extremities of both limbs at l and l, the tube is contracted to prevent the mercury from striking forcibly against the ends by inversion or by violent jolting, by which barometers are liable to be broken. To prevent the same when carrying ordinary barometers which cannot be inverted, they

Fig. 30. *Fig.* 31.



* For the conversion of millimeters into English inches, and of English inches into millimeters, a table will be found at the end of Pneumatics.

Fig. 32.



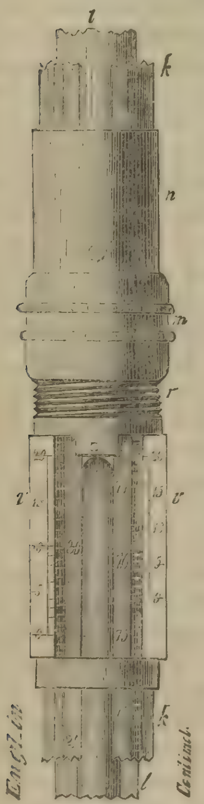
should first be inclined gently till the mercury fills the whole empty space at the top of the closed limb, and then be carried in this position.

80. As by rough travelling, in spite of all precautions, a bubble of air will sometimes get into the tube, to prevent it in such cases from getting into the vacuum at the closed end and thereby spoiling the instrument, when its use may be important, and when it could not be replaced, the above and other similar barometers have sometimes the tube drawn out at some part into a capillary extremity, see *d fig.* 30, and this set and sealed into another tube, which thus forms the continuation of the former. Any small air-bubble, that should find its way into the tube, will then be intercepted at this place, between the capillary termination and the tube surrounding it, where it may remain, doing no harm, until it can be removed by inversion or other suitable or necessary treatment. It, however, increases the liability of the tube to break at this place.

81. Where portability is required in connection with the greatest scientific accuracy, as for *very accurate levelling* purposes, the form represented in *fig.* 32, is used. This Levelling Barometer is a cistern barometer. The sides of the cistern are formed of a short glass cylinder *c*, the edges of which are ground true, the upper being pressed firmly against a wooden (box-wood) top, through the centre of which the barometer-tube passes loosely, being secured to it by an annular piece of kid, the inner edge of which is tied around the tube, its outer edge round the projecting edge of the opening in the cover. The lower edge of the glass cistern is pressed tightly against a wooden ring furnished below with an external screw, on which may be screwed another wooden ring, around which a piece of kid is secured bag-fashion, forming the bottom of the cistern for containing the mercury. The above wooden top and bottom pieces are secured against the glass cistern by two annular brass pieces forced together by three bolts as seen at *c*. The lower brass piece is furnished with a screw, on which may be screwed the brass cylindrical case *h*, having through its bottom a screw, by which the mercury in the cistern may be raised or lowered to the beginning of the scale, indicated by its just touching an ivory point, seen inside the cistern near *p*, projecting downwards from the top of the cistern as described in 64. To the upper brass piece of the cistern, the long upright brass tube *k* is fixed, enclosing the barometer tube, see *t t fig.* 33, containing the mercurial column. To observe this the brass tube, see *k fig.* 32, and *k k fig.* 33, is furnished from its middle upwards with two longitudinal openings on its opposite sides, along the edges of which the scale is engraved, which on the one side may be French Centimetres, on the other English Inches. The arrangement of the sight and vernier or nonius is seen of natural size in *fig.* 33. The sight consists of a ring, the two lower edges of which *z* and the corresponding one on the other side, form the sight-line, which is to be

brought on a level with the top of the mercurial column. For this purpose this ring is attached by the screw r to the piece $m\ n$, of which n slides on the outside of the brass tube $k\ k$, and is moved up and down by the hand, until the sight z is near the top of the mercury. We then turn the piece m, which is movable round the piece n, with which it is connected, and by the fine screw r works on the sight z, so that this latter is moved still further towards the top of the mercury, till at last the light seen between them through the tube *just disappears* in the middle, by their apparently touching each other, when the sight-line z is exactly on a level with the top of the mercury. The highest division, or 20, of both verniers v and v then indicates the point on their respective scales, which corresponds to the top of the mercury. To read this off on the right hand side, the numbers on the scale are French centimetres, divided into tenths. As the vernier has 20 divisions, it subdivides the tenths of centimetres again into twentieths and thus $(10\times20=200)$ gives two-hundredths of centimetres. We therefore obtain the height of the mercurial column by reading off on the main scale the centimetres and tenths to the nearest lower division, which is 77.4, and adding to this the distance from it to the extremity of the vernier, by taking the number of that division of the vernier, which coincides with a division on the scale, being 3 two-hundredths $(\frac{3}{200})$, which by dividing by 2 are converted into one-hundredths $=$ 1.5 hundredths$=$0.015, which added to the above 77.4 gives 77.415 centimetres, or 774.15 millimetres, as the whole height.

Fig. 33.



To read off the left hand side, it will be seen that the scale is divided into inches, tenths, and half of tenths, that is twentieths $(\frac{1}{20}=0.05)$. As the vernier has 20 divisions, it subdivides the twentieths of inches into 20 parts and thus gives $(20\times20=400)$ four-hundredths of an inch. On the main scale we therefore read off the nearest lower division, which is 30.45,

to which we add the distance to the extremity of the vernier, by taking the number of that division of the vernier, which coincides with a division of the scale, being 13 four-hundredths ($= \frac{13}{400}$), which divided by 4 to convert them into hundredths gives 3.25 hundredths = 0.0325, which added to 30.45 gives 30.4825 inches, as the whole height of the mercurial column. It would have been more convenient, if this vernier had contained 25 divisions, so as to subdivide the twentieths of the scale into 25 parts instead of 20, as then the divisions of the vernier would have indicated 500ths so that multiplied by 2 they would be converted into 1000ths of an inch.

The enclosing brass tube of this barometer, *k fig.* 32, contains the bulb of a thermometer *g*, to ascertain the temperature of the mercury in the tube, and which should be read off immediately after adjusting the sight *z*, as the proximity of the observer is apt to increase the temperature, while reading off the vernier. This brass tube is also furnished with two small transverse axes, of which one is at its middle, by which it is suspended when in use by a universal motion in the top *w* of a three-legged mahogany stand, *q q q*. When required to be fixed for transportation the barometer is lowered, so as to be suspended in the stand at *w* by the other or upper axis *a*. The screw at *h* is then turned till the mercury is nearly up to the top of the cistern, the stay-wires *i i i*, are raised, and the legs of the stand which move on hinges are folded together, so as to form an enclosing case around the barometer. The whole is then cautiously turned upside down, and having secured the legs of the stand together by a brass ring, slipped into a leather case.

82. Standard barometers have a similar construction to the Levelling barometer, *fig.* 32, only as they remain permanently fixed in one place, they are generally made of a much larger diameter, so as to avoid altogether the capillary action of the tube on the mercury. Instead of the ordinary sight, they are sometimes furnished with a sliding telescope, moved by a rack and pinion. The vernier which is attached to it, is read off by the aid of a magnifier and is so constructed as to indicate thousandths of an inch.

83. For stationary observatories the mercurial barometer may be made self-registering, the mode and principle of which will be described in another place (see Thermics under Thermometers).

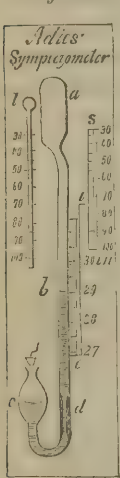
84. Although the changes in the mercurial barometer are small, still with proper precautions, they are always given in the right proportion. The mercurial barometer with the previously described improved means of observing and measuring, constitutes therefore the most accurate instrument which we have for measuring the pressure of the atmosphere, the only objections to it being its weight and liability to break by transportation.

But even in this latter point it has the advantage, that it rarely deceives. To obviate, however, these objections, several substitutes have been invented, which we will now describe.

Substitutes for the Mercurial Barometer.

85. In the mercurial barometer we measure the atmospheric pressure by the weight of the mercury, due to the action of Gravity. Instead of gravity may be substituted the Elasticity of bodies, such as that of permanent gases, of vapors, or of metals.

Fig. 34.

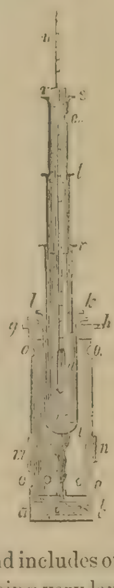


86. In Adie's Sympiesometer (from συμπιεζω (sympiezo), I compress, and μετρον (metron) measure), the elasticity of a confined gas is used to estimate the pressure of the atmosphere. It is made of glass, see *fig.* 34, and has the general appearance of a syphon barometer, but is much shorter, and the closed end *a* considerably enlarged to contain the gas, which should be one that does not act on oil, such as Hydrogen or Nitrogen, generally the former. The bend *d* with part of the open end *c* is filled with oil, which thus confines the gas by separating it from the atmosphere. It will thus be seen, that when the pressure of the atmosphere on the oil in the open end at *c* varies, the volume of the gas in *a* is diminished or increased according to Mariotte's law, and the level of the oil at *b* thereby altered. But the volume of the gas is also altered by the temperature. To correct it for this influence, without the aid of calculation, the scale *e*, which is to indicate from the volume of the gas the pressure of the atmosphere in inches, corresponding to the mercurial barometer, is made movable, its index *i* sliding over another but fixed scale *s*, which contains numbers corresponding to the different temperatures of the gas, as indicated by a delicate thermometer *l*, which is inverted in order to have its bulb near the gas. Before reading off the pressure, the temperature of the gas is observed with great accuracy by the thermometer *l*, and the index *i* of the pressure scale *e* is next placed on the exact number of the fixed scale *s*, which corresponds to the temperature, and the pressure is then read off, as indicated by the level of the oil at *b*, without any further correction. The Sympiesometer is said to indicate the changes in the pressure of the atmosphere much sooner than the mercurial barometer, and is therefore mainly used on board vessels, for prognosticating the sudden and dangerous squalls experienced

in the tropical regions. To prevent the effect of the motion of the vessel, its diameter is often contracted near the bend at *d*. The Sympiesometer in its present form is due to Mr. Adie, of Glasgow, and only those made by him and bearing his name are considered as good and reliable. It has, however, the inconvenience, that the oil is apt to become thick by the action of the air at the open end, by which the working of it is impaired. To prevent the oil from spilling, by transportation, from the open end, this is generally furnished with a stopper, which can be drawn down on it by a wire, projecting from the lower edge of the instrument and furnished with a nut to tighten it.

87. Another substitute, is the Boiling Point Barometer, generally known under the name of the Boiling Point or Hypsometric Thermometer, which acts on the principle of estimating the atmospheric pressure from the elasticity or tension of the vapor, generated from pure water, boiling in an open vessel, which tension is the same as the atmospheric pressure. *Fig.* 35 represents the most approved form, that of Regnault, (Ann de Chimie, 3d ser. Vol. XIV., p. 202.) The instrument is made of sheet brass, and consists of a small cylindrical vessel *l k i*, into the lower closed end of which pure distilled water *w* is introduced. This part is fixed into the top of another cylindrical vessel *g h m n*, the bottom of which is formed of a small spirit lamp *a b*, which fits into it by a catch, and by which the water is made to boil. The necessary draft of air enters through the lower orifices *o o*, and passes out at the upper ones o_1 o_1. *m n* is a sliding ring extending down on one side, by which, in case of windy weather, the lower openings *o o* may be diminished or closed on the side towards the wind. The upper part *r t s* of the vessel *l k i* containing the water, is formed of short sections of tubes, sliding inside of each other, as those of a telescope. The uppermost has an opening o_{11} large enough for the free escape of the steam, and its top is closed by a stopper *v*, through which the stem of the thermometer *u u* slides easily, but safely. The scale of this thermometer is marked on the glass, and includes only about 25° next below the ordinary boiling point, each degree being very large, and divided into tenths and even smaller fractions. Having introduced 2 or 3 cubic inches of distilled water, the alcohol lamp is lighted, so as to cause the water to boil, while the thermometer is constantly adjusted by moving the stem down through the stopper, so that the top of the mercu-

Fig. 35.

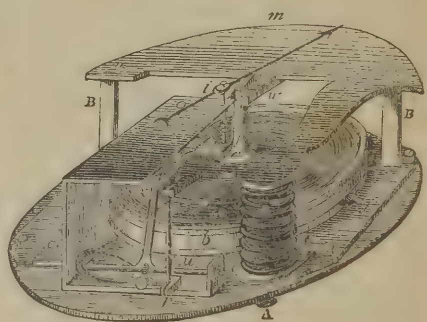


rial column is barely visible above it at *v*, while by sliding the tubes *s t r* up and down, inside each other, the bulb is kept at the distance of about one inch above the water. When the mercury becomes stationary, while the water is all the time boiling, the exact temperature is read off to the smallest possible fraction of a degree. The elasticity or tension of the vapor corresponding to this temperature, is then ascertained from Table VII at the end of Pneumatics. A well-constructed instrument of this kind, will, with all due precaution, give results not varying from those of the Barometer more than from $\frac{5}{100}$ to $\frac{1}{10}$ of an inch, the main source of inaccuracy being the difficulty of graduating a thermometer correctly into so small parts of a degree, and the liability of these to alter by the subsequent irregular contraction of the glass of the bulb and even of the stem. This instrument, being only 14 inches in length when drawn out, is more portable and much easier packed without danger of derangement or breakage, and is therefore often used as a substitute for the barometer on rough travels, to estimate the height of the different elevations, see 94, &c.; but for accurate levellings of small heights it is not suitable. It will be seen from Table VII, that, at 30 inches, barometric pressure, a diminution of $\frac{1}{10}$ degree in the boiling point corresponds to a difference in the atmospheric pressure of about 0.059 inch, and will therefore, when the temperature of atmosphere is 32°, indicate a difference in height of 51.3 feet.

88. In the Aneroid Barometer (the name said to be formed by the inventor from *α* privative and *ρεω* (reo), I flow, intended to mean, without fluid) the atmospheric pressure is measured by the elasticity of a metallic spring. Its general form and size, see *fig.* 36, is that of an ordinary chronometer.

Fig. 36.

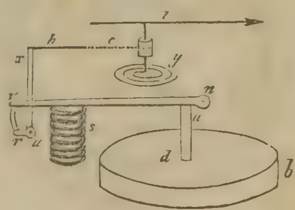
Fig. 37.



Its interior is shown by *fig.* 37. The main part of it is a metallic vacuum

vessel b d, having the form of a very short cylindrical box of about two and a half inches diameter, from which the air has been almost, though not entirely, exhausted through the opening at f, which opening, after effecting the exhaustion, is soldered up. The two ends (top and bottom) of this box are made of thin corrugated sheet copper or brass, strengthened at their middle, one being fastened to the supporting plate of the instrument, while the other d, by the upright rod a, is connected at w with a one-armed lever m n v, resting by its two fulcra at n and n, on the ends of two uprights B B. It will thus be seen, that the atmospheric pressure on the two ends of the vacuum box d, will have a tendency to force them together, and thereby to depress the end v of the lever. To prevent this and to counteract the pressure of the atmosphere on the vacuum box, this end of the lever is supported by a spiral spring s, the other end of which is fastened to a small plate, which rests on the supporting plate of the instrument, but can be raised or lowered by the screw A. It must be evident, that as the pressure of the atmosphere on the vacuum-box increases, it will compress the spring s, and depress the end v; when, on the contrary, it decreases, the elasticity of the spring will again raise it. To show this motion the end v is connected by the rod v r with the arm r, which again is connected with the axis u by a curved spring and the screw z, by which screw the length of its leverage on the axis u may be altered. To the axis u is again attached the other arm x, the two arms r and x, together with the axis u, thus forming an angular lever. From the end of the arm x, a slender rod h terminating in a chain c passes to and round a cylinder, the axis of which at one end is connected with a flat spiral hair-spring y, and at the other end passes through the face of the instrument and carries its index or hand i, which, see *fig.* 36, traverses a graduated circle on the face, which circle is divided into parts marked as inches and corresponding to the height of the mercurial column in an ordinary barometer. Disregarding the peculiar form and exact relative position of the different parts, they may be represented, and their mode of action better understood by a reference to *fig.* 38. When the atmospheric pressure on the vacuum box b increases, it forces the top d of the latter further in; by this the rod a depresses the lever n v, thereby compressing the spring s. The end v of the lever n v, then acts by the rod v r on the angular lever r u x, which again draws the rod h and the chain c, and thereby turns the cylinder, and the hand i, which latter thus moves

Fig. 38.



over the face from left to right, whereby at the same time the spring *y* is slightly coiled. When, on the contrary, the atmospheric pressure on the vacuum-box diminishes, the spiral spring *s* raises the lever *n v*, which, through the angular lever *r u x* slackens the rod *h* and chain *c*, and thus allows the spiral spring *y* to turn the cylinder back again, whereby the index is moved in the opposite direction, from right to left.

To set the hand to correspond with a standard mercurial barometer, it is moved by turning the small screw A, *fig.* 37, the head of which will be found on the back of the instrument. If then the space, moved over by the changes of the atmospheric pressure (its rate of motion), does not correspond with the mercurial barometer, it is adjusted inside by the screw z, see *fig.* 37, which alters the length of the arm *r*. The face of this instrument is generally furnished with a thermometer, see *fig.* 36, the bulb of which is inside, and thus indicates the temperature of the instrument. The inventor of the construction of this barometer, Mr. Vidi of Paris, claims however to have rendered it independent of the influences of the temperature, by leaving a certain, very small, portion of gas in the vacuum-box. The preponderating effect of heat on this instrument, he asserts to be to weaken the elasticity of the vacuum-box and of the spring *s*, and thereby to increase the compressing effect of the atmosphere on the vacuum-box, and that this effect therefore may be counteracted by leaving in it a very small portion of air, just enough to counterbalance, by its increased elasticity by heat, the increased compression of the vacuum-box, in consequence of the diminished elasticity of the spring *s*. To test the instrument for the completeness of this compensation for temperature, it is only necessary, while the atmospheric pressure is found by a mercurial barometer to be stationary, to expose it to two different temperatures, and ascertain its variation, which variation, divided by the number of degrees producing this change, will give the correction for each degree.

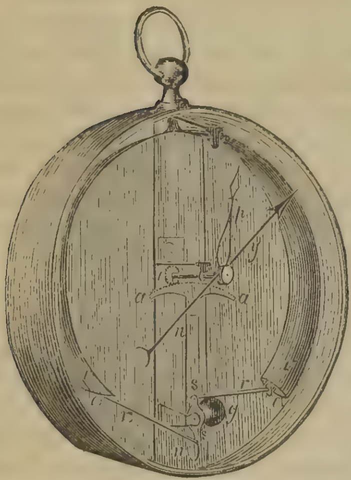
The use of the register-hand *t* is, as in the Wheel-barometer, merely to note the exact place of the hand *i* of the instrument at the last observation, which is done by moving it by the small knob in the centre of the glass covering the face, till it is exactly over it. Inspection at any subsequent time will then easily tell, how much the barometer has risen or fallen.

The complicated construction of this instrument must always render it, for very accurate scientific purposes, inferior to the mercurial barometer. Its extreme portability, being only of the size of an ordinary chronometer, must however prove it to be a useful, and, for many purposes, even a highly valuable instrument. The great objection to it is its liability to get out of order without any previous warning to the observer. When used for

important observations, it should therefore constantly be compared with a good mercurial barometer.

89. The "Metallic Barometer" (Bourdon's) acts on a similar principle. *Fig.* 39 represents its interior arrangement, the face having been removed and the hands replaced. It consists of a flat, hollow, metallic vacuum vessel *v v*, made of very thin sheet brass, of a doubly-arched or lenticular cross-section, as seen at the end *e*, and curved as part of a hoop, so that the two ends *e* and e_1 are only a short distance from each other. The outer side of the vacuum-vessel having a greater extent of surface than the inner, on account of the longer radius of its curvature, the atmospheric pressure on it, which acts at every point in the direction of the radius of its curvature, so as to force it inward, will be greater than the pressure on its inner side, which also acts at every point in the direction of the radius of its curvature, but so as to force it outward. The atmospheric pressure has therefore a constant tendency to increase the curvature of the vacuum-vessel, so as to cause its two ends *e* and e_1 to approach each other, which effect is counteracted by the resistance offered by the elasticity of the vessel itself, so that when the atmospheric pressure increases, it will cause the ends to move still nearer to each other; when, on the contrary, the atmospheric pressure becomes less, the elasticity of the vessel will cause them again to recede from each other. To increase this motion, the ends *e* and e_1 are made to act by the rods *r* and r_1 on the ends of the two-armed lever *s s*, to the axis of which another lever *n n* is attached, the end of which carries a section of a cog-wheel *a a*. This cog-wheel acts on a pinion *i*, the axis of which passes through the face of the instrument, and carries the hand *y*, which is thus made to pass over a graduated circle on the face, the parts of which indicate the corresponding changes in the mercurial barometer in inches. When the atmospheric pressure is increased, the hand *y* is thus made to move from left to right; but when it is

Fig. 39.



decreased, the elasticity of the vacuum-vessel will move it in the opposite direction, from right to left, to assist in which, the small weight g is attached to a short arm, which acts on the axis of the lever $s\,s$, thus assisting in forcing the ends $e\ e_1$ apart. p is the register-hand, which by being placed over the hand y, will indicate, what change has taken place since the last observation.

Nature of the Barometer.

90. The Barometer measures the pressure of the atmosphere. This pressure depends mainly, though not altogether, on the weight of the atmosphere, because in many cases the atmosphere is not allowed to press with its whole weight on account of the lateral or upward currents, which take place in it and constitute what we call winds, while if these currents should meet each other or have a descending direction, it would increase the pressure beyond what is due to its weight. If, in a similar manner, the air near the earth should, from some cause, become suddenly heated, so as to have its elasticity increased, it would require some time to put the surrounding air in motion; this would meanwhile increase the pressure beyond what is due to its weight alone. In this latter case it will also be seen, that the specific gravity or density of the air would *not* be increased. From these considerations, it will be evident, that the barometer cannot correctly be said to indicate the weight or the density of the atmosphere, but only its *pressure.*

91. *The Manometer.* To indicate the changes in the specific gravity or density of the atmosphere, a separate instrument was proposed by Otto Guericke, called the Manometer, from μανος (manos), rare, and μετρον (metron), measure, meaning, measurer of the density of the air.* It consists of two balls of nearly the same weight, but of very different diameters, the one being hollow, the other solid, both suspended to a balance-beam, so as to counterpoise each other in the air. As bodies suspended in a fluid lose as much of their weight, as the volume of the fluid which they displace weighs, it will be seen that the larger ball, displacing a larger volume of air, has, under the above circumstances, lost more of its absolute weight, than the smaller; and that any change in the density of the air will affect it more than the smaller, detracting more from its weight, when the density becomes greater, and restoring to it more of the weight, already lost, when the density becomes less. In either case, therefore, the equilibrium of the balance will be destroyed, the large ball rising when the

* The word Manometer is sometimes, though incorrectly, applied to pressure-guages, see (105), for measuring the tension or elasticity of gases, this latter being considered proportional to their density; but in the confined state, the elasticity is altered by the temperature, while the density is not affected, unless they be vapors in contact with a liquid.

density of the air is increased, and falling when it is diminished. For the same reason, very light and bulky substances, such as feathers, have a perceptibly greater weight than that ascertained in the ordinary way in air. Hence as a puzzle it may be said, that a pound of feathers is heavier than a pound of lead.

Uses of the Barometer.

92. *As a weather-glass.* The most popular use made of the barometer is for *prognosticating the weather.* The weather is said to be bad when either windy, or rainy, or both. Winds are masses of air in motion. Their direction being mostly lateral and upward, their most frequent effect on the barometer is to prevent the air from pressing with its whole weight on it, and thus in most cases to cause the barometer to fall, but not necessarily so, since if the wind have a downward tendency, it will cause the barometer to rise. Rain is most frequently caused by a hot and moist current of air mixing with a cold current or passing over a cold country, or by the ascent of a heated column of air saturated with moisture, in which case the moisture condenses by the cold produced by the expansion of the air, on account of the less pressure as it ascends. Rain thus depends more or less on currents of air, either near the surface of the earth or higher up, which, as we have just seen, will affect the barometer; and thus rain, like wind, generally causes the barometer to fall, but not necessarily so, as it may even have a contrary effect. The condensation of the vapor and its consequent withdrawal from the atmosphere, causes also a certain, but comparatively very small, depression of the barometer. As thus changes in the barometer nearly always accompany changes in the weather and frequently precede them by more or less time, this instrument serves as an excellent guide to account for present, and even to anticipate coming changes in the weather.

The Wheel and other cheap barometers constitute, therefore, the common and most popular Weather-Glass, and for this purpose instrument-makers have affixed to different parts of the scale certain inscriptions, indicative of the weather, viz. "Fair," at the average stand of 30 inches; "Change," at 29.5; "Rain," at 29; "Much Rain," at 28.5, and "Stormy," at 28; while above 30 inches we find "Set Fair," at 30.5, and "Very Dry," at 31 inches. These inscriptions are very fallacious, and have done much harm by bringing the barometer in disrepute and calling the attention away from the real scale of the instrument, which indicates the height of the mercurial column. For although the most severe gales are generally accompanied by rain and cause the lowest stand of the barometer, much rain and bad weather may also occur at a high stand, where therefore the inscriptions indicate fair weather. Even for such one-sided use of the

barometer, it would be better, instead of having or looking at the inscriptions, to note whether the barometer is in the act of falling or rising, since even at a high stand a considerable fall is most likely to bring about a change in the weather, although the fall might not reach the ominous inscriptions on the "Weather-glass," while, on the other hand, immediately after a storm, fine weather often appears before announced by the glass. To find whether a rise or fall has taken place since the last observation, most "glasses" are furnished with a register-hand, which is placed by the observer over the hand of the instrument, but which register-hand, in many cases, is much larger and more conspicuous than the index-hand itself, so as to attract the sole notice of casual observers, and, by being mistaken for the hand of the instrument, gives them the idea of a stand still in the instrument, when they most expected a change. It is given as a rule, that a change in the weather, accompanied by a gradual and slow change in the barometer, is likely to last longer than those changes, which are indicated by a sudden change in the barometer.

From the nature of the barometer, as explained in 90, an intelligent observer will, therefore, no more expect bad weather to follow invariably a fall or low stand of the barometer, or good weather to accompany invariably a rise or high stand, than he would expect one kind of weather to follow invariably a wind from the east, and the opposite kind, one from the west. He will know that changes may occur, which not at all or but slightly affect the barometer, and in such cases he will rely on other indications. On the other hand, while from a change in the barometer he will not expect invariably a change in the weather, still he will know, that in such cases causes are active, which *may* bring about such changes. He will consult the Hygrometer (164), to ascertain whether the amount of moisture is at the same time increasing or decreasing; the Thermometer, to observe any simultaneous change in the temperature; and, above all, by constant and attentive observation and by careful study of previous records, he will become familiar with the habits of different winds, at the different seasons of the year, and in the particular localities. Thus he may find that in the fall of the year, after a long and continued spell of dry and fine weather, a change is often anteceded by a rise in the barometer instead of a fall; that certain directions of winds are more apt than others to bring about a fall or rise without a corresponding change in the weather; that certain storms, which by careful attention he will be able to distinguish, are preceded by a fall, as many of the most violent and sudden tropical gales, others by a rise, and others again will at first cause a fall, but then a subsequent rise will indicate their increased violence, &c. &c. In fact, to unprejudiced minds, the barometer has the advantage over all other meteoro-

logical instruments, that it indicates changes in the equilibrium of the atmosphere, while they are often yet far distant from the place of the observer; and thus not only puts him on his guard against them, but also, more than any other instrument, guides him in finding and studying their causes and their progress.

93. As a general rule the barometer is much less variable in the Tropical and Torrid zones than in the more northern latitudes. Thus, in Peru the range of its variations is only about $\frac{1}{3}$ inch, while in London it is about $2\frac{1}{2}$ inches, and in St. Petersburg over 3 inches. The average stand of the barometer at the level of the sea at 45° latitude is 30 inches (or more correctly 29.922 inches), which is considered as the standard pressure for measuring gases, and to which, therefore, their volume is always referred (100). It is somewhat higher near the Tropics, from which latitude, therefore, the average stand of the barometer decreases both towards the equator and towards the poles. The average stand of the barometer at any particular place inland depends mainly on its elevation above the level of the sea, but is also influenced to some extent by the latitude, and by the particular conformation of the whole continent, or that part of it where it is situated. The average stand of the barometer at Philadelphia is 29.95 inches. The barometer is subject to monthly variations, the greatest monthly mean pressures being those for June and January; the lowest, those for November and March. At moderate latitudes, the average difference between the means of June and November amounts to about 0.11 inch. The barometer also exhibits a regular diurnal variation, standing highest at nine o'clock A. M. and P. M., and lowest at three o'clock P. M. and A. M., being unaffected by it at noon. The hours of nine and three, or at twelve, are therefore recommended as most suitable for regular meteorological observations of the barometer. The average of this daily variation, which is ascribed to the *heat* of the sun, amounts in moderate latitudes to about 0.03 inch, but increases towards the equator to 0.1 inch; in higher latitudes it is lost in the irregular changes.

94. *For Measuring Heights or Levelling* (Hypsometry, from ὕψος (hupsos), height, and μετρον (metron), measure). If the atmosphere were of uniform density throughout its whole extent, the height of the mercurial column in the barometer would afford us an easy means of calculating the perpendicular height of the whole atmosphere, or of any part of it, from the known laws of Hydrostatics, that the heights of columns of different liquids, equilibrating each other in communicating tubes, are inversely as their specific gravities. Hence it would only be necessary to multiply 30 inches by 11000, which is the number expressing how many times mercury is heavier than air,

in order to obtain the height of the whole atmosphere in inches, which would make it about 5.12 miles; and in the same manner the perpendicular height of any intermediate part of the atmosphere, between two places not situated on the same level, would be obtained by multiplying the difference in the stand of the barometer at these two places by the same number, 11000. But this is not the case. It has already been stated in 27, that from other experience it is known that the atmosphere extends much farther; and both reason and experience tell us, that as we ascend into the atmosphere, the strata below are not capable of exercising any pressure on those above, and that the upper strata, therefore, are subject to less pressure and consequently have also less density. In this manner both the pressure and the density of the atmosphere must decrease, as we ascend from the level of the sea to greater elevations: still, knowing the exact ratio between the different heights to which we ascend into the atmosphere, and the decrease in the corresponding pressures, the barometer will yet afford us one of the most valuable means to ascertain the differences in level of different places.

95. To understand the principle on which this is ascertained, it may be stated, that while the different perpendicular heights above the surface of the earth, if counted from the upper sensible limit of the atmosphere down to its lower limit at the level of the sea, form an increasing arithmetical progression (1 ft., 2 ft., 3 ft, 4 ft., &c., from the top of the atmosphere), the corresponding pressures on the barometer form an increasing geometrical progression. Between any two such series there is a similar relation as between the ordinary logarithms and their corresponding numbers, the logarithms forming an arithmetical series, and therefore corresponding to the distances from the top of the atmosphere; while the numbers, to which they are the logarithms, form a geometrical progression, and therefore correspond to the barometric pressures. If, therefore, at the same time or moment, we ascertain in two different places, situated at different heights or on different levels, the true barometric pressures, that is, the heights of the mercurial columns, corrected for the influence of the temperature (77), and then from an ordinary table of logarithms take the logarithms corresponding to these two pressures (it matters not whether the pressures be expressed in English inches or in French millimeters), these two logarithms will indicate the relative distances of those two places from the upper limit of the atmosphere, and may, therefore, by multiplying them by a constant number, be made to give these distances in English feet or any other measure. These distances, deducted from each other, will then, of course, give the difference in their level, or the height of the one above the other. To avoid the double multiplication of the two logarithms by the

constant, the logarithms may first be deducted from each other, and their difference multiplied by it, which will then give the difference in their level.

To obtain these distances from what may, *with sufficient accuracy for present purposes*, be considered the upper sensible limit of the atmosphere, *in English feet*, the constant number by which we multiply the logarithms of the true pressures, is 60158.5, the temperature of the atmosphere being supposed to be 32° Fahrenheit, *and the difference between the logarithms of the true barometric pressures, multiplied by this number, will therefore at once give the corresponding difference in level in English feet, the temperature of the intermediate column of atmospheric air being* 32°.

To facilitate these calculations, tables have been constructed, which give the different distances from the above assumed upper limit of the sensible atmosphere, calculated in this manner for all the different barometric pressures. These distances for pressures from 28 to 31 inches will be found in Table III at the end of Pneumatics, page .

But the above distances are only correct for the standard temperature of the atmosphere of 32°. As air expands by heat, and thus, with the formation of an additional quantity of vapor of water, diminishes its density or specific gravity for every degree of Fahrenheit by 0.00222 of its density at 32°, the same mercurial column will, at higher temperatures, counterbalance a proportionally higher column of air. The temperature of the atmosphere must, therefore, always be ascertained at the same time that we observe the pressure, by an accurate thermometer, which has been sufficiently long exposed to it in a suitable place. Should the temperatures at both places not be the same, their average is taken as the temperature of the column of air between them. If then this average temperature be not 32°, a correction must be applied to the above difference in level or height, which correction is obtained by multiplying the above given expansion of the atmosphere for 1° Fahrenheit, 0.00222, first, by the number of degrees which the average temperature of the air is above or below 32°, and then by the above-obtained height for 32°, which correction is to be added, if the average temperature of the air be above 32°, and deducted, if below; or, calling the above height, corresponding to 32°, h_{11}, and the temperatures of the air at the two places or stations, T and T_1, the

$$\text{Cor. for temp. of the air } \textit{above } 32^\circ = +\,0.00222\left(\frac{T+T_1}{2} - 32^\circ\right)h_{11},$$

$$\text{Cor. for temp. of the air } \textit{below } 32 = -\,0.00222\left(32^\circ - \frac{T+T_1}{2}\right)h_{11}.$$

It will be seen that this correction is quite considerable. Thus at a barometric stand of 30 inches, a fall of $\frac{1}{10}$ inch corresponds at 32° to a difference in level of 87.2 feet, but at 80°, this correction for temperature

of the air being $= + 0.00222 \times (80° - 32°) \times 87.2$ feet $= 9.3$ feet, it will correspond to a difference in level of 96.5 feet.

Two other, but comparatively small, corrections are yet to be applied to the thus corrected height, on account of the decrease of gravity: 1. from the poles toward the equator, 2. from the level of the sea upward into the atmosphere, by which the weight of the mercury becomes less, and the same column of mercury will thus counterbalance a smaller column of air. These corrections for latitudes near 45°, and for small heights, are often for ordinary amateur purposes entirely disregarded. They will be given by Tables IV and V at the end of Pneumatics. The first of them depends, as stated, on the latitude; and taking gravity and the consequent weight of the mercury at 45° latitude as standard or unit, we obtain this correction by multiplying 0.0028371, first by the cosine of the double latitude, and then by the last-obtained height, which correction, as indicated by the sign of the cosine, is to be deducted for latitudes greater than 45°, and added for those less than 45°; or, calling the obtained height, corrected for temperature of air, h_1 and the latitude L, this

$$\text{Cor. for Lat.} = 0.0028371 \cos. 2\,\text{L}.\, h_1 \begin{cases} \text{Add for Lat. smaller than } 45°. \\ \text{Deduct for Lat. greater than } 45°. \end{cases}$$

If the two places have a sensible difference of latitude, the average latitude is used. The second correction for gravity depends on the height or altitude itself, and is obtained by first adding to the obtained height the number 52252, then dividing by the mean radius of the earth, 20886861 ft., and then again multiplying by the height, which correction is always to be added, as on account of the less weight of the mercury, the upper portion of the atmosphere has given too great a column of mercury and thereby caused too small a difference in pressure. Calling the height corrected for temperature of the air and for the latitude, h_0, the

$$\text{Cor. for altitude} = + \frac{h_0 + 52252}{20886861} h_0.$$

Calling the true height or difference in level of two places, h, the barometric pressures at those places corrected for temperature of the mercury and of the scale, B and b, the following formula will give all the different operations:

$$h = (\text{Log. B} - \text{log. b}) \times 60158.5 \text{ ft.} \times \begin{cases} 1 \begin{matrix} + 0.00222 \left(\frac{T+T_1}{2} - 32°\right) \\ \text{or} \\ - 0.00222 \left(32° - \frac{T+T_1}{2}\right) \end{matrix} \\ 1 + 0.0028371 \cos. 2\,\text{L} \\ 1 + \frac{h + 52252}{20886861} \end{cases}$$

96. To illustrate the above by an example, we may select the calculation of the height attained by Gay Lussac in his famous balloon ascension from Paris in 1804, being the greatest height ever attained in this manner.

Observed height of Barometer	*Temp. of Merc.*	*Temp. of Air*	*Lat.*
In Balloon $= 12.945$ inch $= b_1$	$14°.90 = t_1$	$14°.90 = T_1$	$48°50' = L$
At Paris $= 30.145$ inch $= B_1$	$87°.44 = t$	$87°.44 = T$	

Applying the corrections for temp. of the mercury and of the scale (77), we obtain the

True height of Barometer

$$\textit{In Ball.} = b_1 \left.\begin{array}{l} + 0.0001001\,(32° - 14°.90)\,b_1 \\ - 0.0000104\,(62° - 14°.90)\,b_1 \end{array}\right\} = 12.961 \textit{ inch} = b$$

$$\textit{At Par.} = B_1 \left.\begin{array}{l} - 0.0001001\,(87°.44 - 32°)\,B_1 \\ + 0.0000104\,(87°.44 - 62°)\,B_1 \end{array}\right\} = 29.983 \textit{ inch} = B$$

$$\textit{Log. } B = \textit{Log. } 29.983 = 1.4768747$$
$$\textit{Log. } b = \textit{Log. } 12.961 = 1.1126365$$
$$(\textit{Log. } B - \textit{Log. } b) = 0.3642382 = \textit{Difference of Logs.}$$

Difference of Logs. multiplied by 60158.5

$$= 0.3642382 \times 60158.5 = \qquad 21912.03 \textit{ feet} = h_{11}$$

$$\textit{Average Temp. of Air} = \frac{T + T_1}{2} = 51°.17$$

$$\textit{Cor. for Temp. of Air} = + 0.00222 \left(\frac{T+T_1}{2} - 32°\right) h_{11}$$

$$= + 0.00222 \times 19°.17 \times 21912.03 \textit{ feet} = \qquad + 932.52 \text{ “}$$

$$\textit{Height of Balloon, cor. for Temp. of Air} = 22844.55 \textit{ feet} = h_1$$

$$\textit{Cor. for Lat.} = 0.0028371 \cos.\ 2\ L.\ h_1$$
$$= - 0.0028371 \cos.\ 97°40' \times 22844.55 \textit{ feet.}$$
$$= - 0.0028371 \times 0.1334097 \times 22844.55 \textit{ feet} = \qquad - 8.65 \text{ “}$$

$$\textit{Height of Ball. cor. for Temp. of Air and for Lat.} = 22835.90 \textit{ feet} = h_0$$

$$\textit{Cor. for Altitude} = + \frac{h_0 + 52252}{20886861} h_0$$

$$= + \frac{22835.90 + 52252}{20886861} \times 22835.90 \textit{ feet} = \qquad + 82.09 \text{ “}$$

$$\textit{Height of Balloon above Barometer at Paris} = 22917.99 \textit{ feet} = h$$

Add height of Barometer at Paris, above level of sea, 159.78

Height of Ball. above the level of the sea, = 23077.77 *feet,*
or 4.37 *miles.*

By the aid of Logarithms these calculations are considerably facilitated.

97. To obtain the same differences in level in French metres, the constant number for multiplying the difference of the logs. of the two true barometric pressures (being in this case generally obtained in millimetres) is 18336. The expansion of the air by heat and by the addition of vapors, being for every degree *Centigrade* 0.004, the correction for temperature is 0.004 $\frac{T+T_1}{2} h_{11} = \frac{2(T+T_1)}{1000} h_{11}$, to be added for temperatures above, and deducted for temperatures below 0°, as indicated by the sign of $(T+T_1)$; the correction for latitude is of course the same, and that for altitude is $+ \frac{h_0+15926}{6366200} h_0$, the whole formula being

$$h = (\log B - \log b) \times 18336 \text{ metres} \times \begin{cases} 1 + \frac{2(T+T_1)}{1000} \\ 1 + 0.0028371 \cos. 2\,L \\ 1 + \frac{h+15926}{6366200} \end{cases}$$

To obtain these different heights in metres almost entirely by the aid of Tables, the reader is again referred to Meteorol. Tables by Guyot, published by Smithsonian Inst. To facilitate the conversion of French metres into English feet, and of English feet into French metres, Table VI will be found at the end of Pneumatics.

98. By calculating in the above manner the height corresponding to a barometric pressure of 15 inches, we obtain the height of about 18000 feet or 3.4 miles as that, at which the density of the atmosphere is only one-half of its density at the level of the sea; and as the densities increase in the same geometrical progression as the pressures, it follows that if we leave out of consideration the effect of the rapid diminution of the temperature of the atmosphere as we ascend higher, both the pressure and the density of the atmosphere ought to become one-half less for every additional 3.4 miles.

99. For the estimation of the difference in level of two places from the barometric pressures, only the most accurate instruments, such as the Levelling Barometer described in 81, *figs.* 32 and 33, should be used. As the barometric pressure of the atmosphere is constantly changing, it is necessary to observe the pressures at the same moment in both places, for which purpose, therefore, two instruments are required, the moments for observing being indicated by signals or by chronometers. Where this cannot be done, and the two places are at no very great distance from each other, the observer may travel with his instrument from the one place to the other, and then immediately back again to the first station, and if any change has occurred, take for this station the average of the two observa-

tions. If the two places are very distant from each other, the average stand of the barometer, derived from observations for a length of time, also affords data from which the difference in their level is often estimated. As the ordinary variations of the barometer, leaving out the extremes, which occur only at considerable intervals, rarely exceed even in moderate latitudes $1\frac{1}{2}$ inch, and become much less as we approach the equator (93), observations with the barometer, performed on a single journey over a mountainous country, where therefore the differences in the elevations and the consequent differences in the barometric pressures are very great, will afford data sufficiently accurate for an approximate estimation of these elevations; and the barometer is therefore the instrument commonly employed for this purpose, the form combining the greatest portability with sufficient accuracy being that of Gay-Lussac's, described in 79. The Boiling-Point Barometer described in 87, though less accurate, has been found to give available results. The Aneroid and Metallic Barometers, being the most portable of all, have not yet been sufficiently tested for such purposes.

100. *For estimating the true volume of gases, and from it, their weight.* Another use of the barometer, for which it is constantly required in a chemical laboratory, is in estimating the weight of a gas from its volume. As the volume of a gas varies with the pressure on it, it becomes necessary, when its volume is observed for the purpose of estimating its quantity or weight, to note the pressure by which it is confined, and then to reduce the observed volume to what it would be at a *standard pressure*, which is assumed at 29.9218 inches of mercury (760 milimetres), this being the average stand of the barometer at the level of the sea at 45° latitude (93), and which number is used for all important estimations, serving as a basis for other calculations, such as the exact weight of 100 cub. inch. of air (57), but for most ordinary purposes 30 inches is taken as sufficiently accurate. Suppose, thus, that the volume of a gas, confined in a graduated glass tube by mercury or water contained in a pneumatic cistern (   ), be found by the graduation of the tube to be 24 cubic inches, when the barometer stands at 29 inches, the level of the confining liquid being the same inside the tube as outside. We then have by Mariotte's law (44), that

$$\text{24 cubic in. (vol. at 29 in.)} : x \text{ (vol. at 30 in.)} :: \frac{1}{29} : \frac{1}{30},$$

$$\text{therefore: } x = 24 \text{ cubic in.} \times \frac{29}{30} = 23.2 \text{ cub. inches}$$

which is the volume the gas would occupy at the standard pressure of 30 inches. If the level of the confining liquid should not be the same inside the tube as outside, but for instance higher, this column, being supported

by the atmospheric pressure, must of course be deducted from its pressure on the gas. Thus, suppose the confining liquid to be water, the volume of the gas, as before, 24 cubic inches, and the barometer 29 inches, but the water inside the tube 2.9 inches higher than outside. By dividing the latter by 13.6 (the specific gravity of mercury), we find this column of water to be equivalent to 0.21 inch of mercury, which, deducted from the observed atmospheric pressure of 29 inches, leaves 28.79 inches of mercury, as the pressure on the gas; 24 cubic inches, at 28.79 inches' pressure, are then reduced to the standard pressure of 30 inches as above, by multiplying by the former (the observed pressure), and dividing by the latter (the standard), $= 24$ cubic inches $\times \frac{28.79}{30} = 23.032$ cubic inches. In the latter case, however, where a gas is measured over water as confining liquid, the thus obtained volume includes the portion of vapor of water, which is always formed by evaporation and adds its volume, which depends on the temperature, to that of the gas. To avoid this error, it is only necessary, in reducing the observed volume to the standard pressure, to deduct from the atmospheric pressure also that portion of it, which is sustained by the tension of the vapor, and which is obtained by taking from Table IX, the maximum tension of vapor of water corresponding to the observed temperature of the gas. Thus, suppose in the above case, the temperature of the gas to be 79° Fah., we then find from Table IX that the maximum tension of vapor of water corresponding to this temperature, is 0.99 inch. From the whole pressure of the atmosphere, 29 inches, we then deduct, not only as before, the portion sustained by the column of water above the level outside, equivalent to 0.21 inch of mercury, but also that, sustained by the tension of the vapor, 0.99 inch, which thus leaves only $29 - 0.21 - 0.99 = 27.80$ inches as the real pressure on the gas. The volume of this, without the vapor of water, at 30 inches, will therefore be $= 24$ cubic in. $\times \frac{27.80}{30} = 22.24$ cub. inches.

This volume must then also be reduced to the *standard temperature* (see Thermics, under Expansion of Gases), which is assumed in England at 60°, but in most other countries at 32°. This is done by multiplying the volume of the gas by $1 + 0.002178 \times$ *Stand. Temp.*, and dividing it by $1 + 0.002178 \times$ *Obs. Temp.** Thus, for the above 22.24 cub. in. of

* If 32° Fah. be adopted as the standard Temp., the reduction to this from any higher degree t is more conveniently performed by dividing the volume by $1 + 0.00203611\,(t - 32°)$; the coefficient of expansion for 1° Fah. referred to the volume at 32° as unit being 0.00203611. Thus, in this case: $\frac{22.24 \text{ cub. in.}}{1 + 0.00203611\,(79° - 32°)} = 20.298$ cub. inches.

79° temperature, we have its volume at the standard temperature of 32°

$$=22.24 \text{ cub. in.} \times \frac{1+0.002178 \times 32°}{1+0.002178 \times 79°} = 20.298 \text{ cub. in.}$$

For the *true* volume V, of a gas, we thus have the following formula,

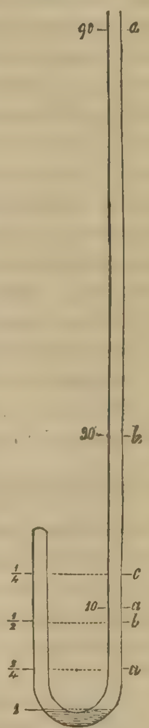
$$V = V_1 \times \frac{b}{B} \times \frac{1+0.002178 \times T}{1+0.002178 \times t}$$

V_1 being the observed volume; b = the true (77) barometric pressure, with deduction, if necessary, for any inequality in the level of the confining liquid and for admixture of vapor of water; B = the standard barometric pressure to which it is to be reduced; t = the temperature of the gas; T = the standard temperature to which it is to be reduced; and 0.00217802 = the expansion for 1° Fah. referred to the volume at 0° as unit.

Having thus reduced the volume of the gas to the standard pressure and temperature, its weight is then easily obtained, if it be atmospheric air, by multiplying the number of cubic inches thus found, by the weight of 1 cubic inch of atmospheric air of the same standard pressure and temperature, and which has been given in 57. If the gas be any other than atmospheric air, we obtain its weight by multiplying the weight, thus found for atmospheric air, by the specific gravity of the gas, referred to atmospheric air as a unit, see 58. Thus, if the above 20.298 cub. in. be Nitrogen, we have its weight:

$$= 20.298 \text{ cub. in.} \times 0.325868 \text{ grs.} \times 0.97137$$
$$= 6.425 \text{ grains.}$$

Fig. 40.



Experiments to prove Mariotte's Law.

101. Having now become familiar with the pressure of the atmosphere and the means of estimating it, we may again revert to the compressibility and elasticity of gases, and describe the experiments, by which the law already stated in 44 was established by its discoverer, Mariotte, after whom it has been called Mariotte's Law. He enclosed a quantity of air in a tube bent as the letter J, or as it is technically termed, in the shape of an inverted syphon, see *fig.* 40, the short limb of which was sealed and graduated into volumes, but the long one left open and furnished with a scale measuring inches. Mercury was then poured into the open end, so as to fill the bend to 1,

thereby enclosing a certain volume of air in the short limb, without its standing with a higher level in the open limb. Under these circumstances, the enclosed air, the volume of which we will call 1, is only under the ordinary atmospheric pressure, say 30 inches of mercury. More mercury was then poured gradually into the open limb, by which the air in the closed limb became more and more compressed. The height of the mercury in the open limb, above its level in the closed limb, was then carefully observed, and compared with the corresponding volume of the air in the closed limb itself. It was thus found, that when the air was reduced to $\frac{3}{4}$ of its original volume, the height of the mercury in the open limb above its level in the short limb, from a to a, measured 10 inches, to which must be added the ordinary atmospheric pressure of 30 inches, in order to obtain the whole pressure on the gas, making it equal to 40 inches of mercury or $1\frac{1}{3} = \frac{4}{3}$ Atmosphere's pressure (61). More mercury was then poured into the open end, till the volume of the air was reduced to $\frac{1}{2}$, when the height of the mercurial column, from b to b_1, producing this effect, was found to be 30 inches, or 1 Atmosphere, which, added to the pressure of the atmosphere itself, made the pressure on the enclosed air 2 Atmospheres. In the same manner, the column $c\,c_1$, when the volume was reduced to $\frac{1}{4}$, was found to be 90 inches, which being 3 Atmospheres, added to the pressure of the atmosphere itself, made the pressure on the gas 4 Atmospheres. The different volumes of the air were thus found to be as $1 : \frac{3}{4} : \frac{1}{2} : \frac{1}{4}$, while the pressures corresponding to them, were as 1 Atmos. : $\frac{4}{3} : 2 : 4$, that is, the volumes occupied by the air were inversely proportional to the pressures on it.

Fig. 42.

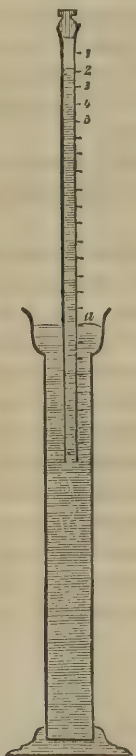
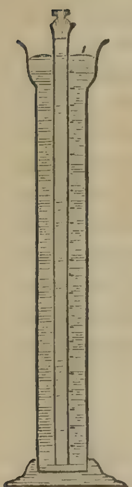


Fig. 41.



102. To prove the same law for smaller pressures than one Atmosphere, a graduated straight tube, see *fig.* 41, open at its lower extremity, and furnished with a screw-stopper at its upper extremity, is immersed with its open end into a deep glass jar containing mercury, until only a certain known volume of air is left at its upper end. This volume we will call 1. The tube

being yet open, and the mercury having the same level inside and outside, this volume of air must of course be under the same pressure as the rest of the atmosphere, that is, under 1 Atmosphere's pressure. The tube is then closed and raised out of the mercury, until the volume of the enclosed air is increased to double its former volume, see *fig*. 42. The mercury will then be found to stand much higher inside the tube than the level *a* outside it in the jar. This height, from *a* to 2, is then measured, and will be found to be 15 inches, which, being supported by the atmosphere, must of course be deducted from the ordinary atmospheric pressure of 30 inches, in order to obtain the pressure on the gas in the tube, which, therefore, will be $30 - 15 = 15$ inches of mercury, $= \frac{1}{2}$ Atmosphere. The tube may then be raised still higher out of the mercury, until the enclosed air acquires 4 times its original volume, when the height of the mercurial column, raised above the level outside, will be found to be $22\frac{1}{2}$ inches, which deducted from the atmospheric pressure of 30 inches, leaves of this only $7\frac{1}{2}$ inches or $\frac{1}{4}$ Atmosphere, as the pressure on the gas. We thus find in these experiments, the volumes of the enclosed air to be as 1 : 2 : 4, while the pressures are as 1 Atmosphere : $\frac{1}{2}$: $\frac{1}{4}$, or, as before, the volumes are inversely proportional to the pressures.

103. A tube similar to any of the above, closed at one end, and containing a portion of air confined by mercury, is often designated by the name of a *Mariotte's tube*.

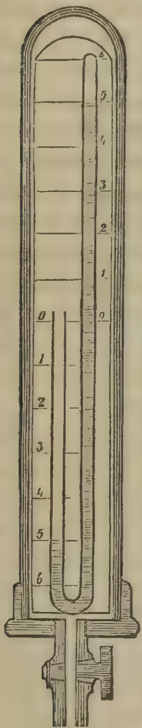
104. The above experiments have since been extended with atmospheric air from $\frac{1}{300}$ Atmosphere's pressure to that of 27 Atmospheres (139) and more, and Mariotte's law confirmed to this extent. But it has also been found, that this law strictly applies only to permanent gases, and to such liquefiable gases as are remote from their point of liquefaction, but that as soon as they approach the latter, their volume will diminish by increased pressures in a somewhat greater ratio. This has been found to be the case with Sulphurous acid and several others. In the same manner, even Carbonic acid, if cooled to 32°, has been found to expand by diminished pressures more than it ought according to Mariotte's law, or more than atmospheric air does. This is probably also the reason, why most compound liquefiable gases and vapors are found, by experiments, to have a somewhat greater specific gravity than that calculated from the volumes of their component ingredients.

Pressure-Gauges.

105. Instruments on the principle of the Barometer or Mariotte's tube, are often used for measuring the tension and elasticity of gases, or the pressure which they exercise when confined (see 117). Such instruments

are called *Pressure-Gauges*, sometimes *Manometers* (see note to 91). *Fig.* 43 shows, on an enlarged scale, the Mercurial Exhaustion-Gauge, *m*, attached to the double-barrelled Exhausting Air Pump, *fig.* 6, to indicate the quantity of air remaining at any time during the exhaustion, by the tension or pressure which it exercises, and to which its quantity is proportional. It will be seen, that it is an abridged or shortened syphon barometer, which is enclosed in a small separate receiver, connected with the passage leading from the barrels *a* and *b* *fig.* 6 to the large receiver *h*. From an inspection of *fig.* 43, it will easily be seen, that the closed limb, being only 12 inches long, will exhibit no Torricellian vacuum, but remain filled with mercury, to the top, until the tension or pressure, which the air in the receiver is capable of exercising on the mercury in the open limb, is reduced to 12 inches of mercury, and therefore the density of the air is only $\frac{12}{30}$ or $\frac{2}{5}$ of its original density, $\frac{3}{5}$ having been removed; after which all further rarefaction will be indicated by it, the amount of air remaining at any time, being given as a fraction, which has for its numerator the mercurial column sustained by it in the gauge, and which is measured by the perpendicular height between the levels of the mercury in the two limbs as stated in 65, and for the denominator the whole atmospheric pressure as indicated by the barometer at the time, and which may be assumed at 30 inches. Thus, when the gauge indicates 10 inches as in the figure, the remaining air is $\frac{10}{30}=\frac{1}{3}$ of its original amount, and when the gauge indicates $\frac{1}{10}$ inch, the remaining air is $\frac{\frac{1}{10}}{30}=\frac{1}{300}$.

Fig. 43.



106. For measuring pressures *larger* than the ordinary atmospheric pressure, Mercurial Pressure-Gauges receive the forms represented in *figs.* 44 and 45. *Fig.* 44 has the general form of a cistern barometer, but the cistern *c* containing the mercury is closed air-tight at the top and made to communicate with the vessel, in which the gas is confined, by a small tube, passing from the top, or as *a fig.* 44, through the bottom to above the level of the mercury. The tube *b* is open at the upper end, and the pressure, therefore, estimated by the height of the column of mercury, which is forced up in it, for which purpose it is furnished with a scale measuring inches, 2 inches being equivalent to 1 pound on the square inch. *Fig.* 45 exhibits another pressure-gauge, which is easily constructed out of

a glass tube by bending it twice. The pressure is measured by the difference between the two levels of the mercury in the two limbs (65). For measuring very small pressures, such as that under which ordinary lighting gas is forced through the burners from the pipes, it is made to contain water instead of mercury, in which case for *great* accuracy the tube should be ½ inch in diam. and each limb furnished with a vernier. As the tube of this kind of pressure-gauges is open towards the atmosphere, and the mercurial column in it, therefore, subject to the atmospheric pressure, it is necessary, in order to obtain the whole tension or elasticity of the confined gas, to add to the above pressures indicated by the mercurial column in the gauges, the ordinary atmospheric pressure, but this is often omitted, and the pressure only given as being over and above the outer atmospheric pressure.

Fig. 44.

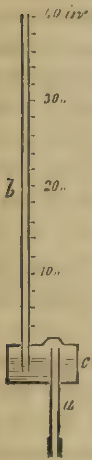
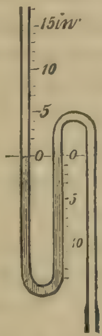
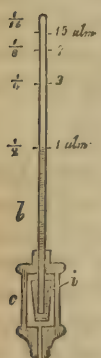


Fig. 45.



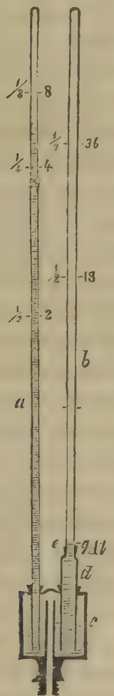
107. The above mercurial gauges, in which the pressure is measured by the height of the column of mercury, which it can sustain, are the most reliable of all, but they have the serious inconvenience, that when the pressure becomes large, for instance in high-pressure steam-boilers, where it often exceeds 60 pounds to the square inch, or 4 Atmospheres, the tube must be more than 4×30 in. $=10$ feet long (see 139). For such high pressures *Condensed Air or Mariotte's Tube Gauges* are often substituted, acting on the principle of estimating the pressure from the volume of a confined portion of air. Any of the above gauges *figs.* 44 and 45 may be converted into such by closing the upper end of the tube, so as to confine the portion of atmospheric air which is contained in it, which volume is then divided into fractions. *Fig.* 46 exhibits a gauge of this kind, such as is used by gas-fitters to prove by high pressure the tightness of gas pipes. For small pressures the tube is left open at the top, and it then acts as one of the above-described mercurial gauges. When used, it is screwed on the end of one of the pipes, into which air is forced by a forcing pump. Any leakage is indicated by the gradual diminution of the pressure. For convenience in the making of it, the cistern c is made of brass; but as this is corroded by mercury, the latter is contained in an iron cup i, placed inside. The cover into which the tube b is cemented, is made to screw on air-tight. The compressed air, the elasticity of which

Fig. 46.



we want to measure, finds its way between the cup *i* and the inside of the cistern *c*, so as to press on the top of the mercury, which, being forced up into the tube *b* closed at the upper end, will compress the atmospheric air which it contains, from the volume of which the pressure is ascertained. Thus, when its volume is reduced to $\frac{1}{2}$, the pressure on it is 2 Atmospheres, or 1 Atmosphere over the ordinary atmospheric pressure; when compressed to $\frac{1}{4}$, the pressure is 3 additional Atmospheres over the ordinary atmospheric pressure; when compressed to $\frac{1}{8}$, 7 additional Atmospheres. To these pressures must, however, be added, in order to find the pressure or elasticity of the confined gas, which we want to measure, the column of mercury inside the tube above the level in the cup *i*. Thus, if the height of this be 6 inches, when the volume is $\frac{1}{2}$, the elasticity of the confined gas is $\frac{6}{30}=\frac{1}{5}$ Atmosphere more than indicated by the volume of the air in the tube, or altogether $1+\frac{1}{5}$ Atmosphere, $=$ 36 inches of mercury, or 18 pounds to the square inch; if 9 inches, when the air is compressed to $\frac{1}{4}$, the whole pressure is $3+\frac{9}{30}$ Atmospheres; if $10\frac{1}{2}$ inches, when compressed to $\frac{1}{8}$, $7+\frac{10\frac{1}{2}}{30}=7\frac{21}{60}$ Atmospheres, &c. It is a matter of course, that if the temperature be not constant, its effect on the confined air in the tube must also be taken into consideration, by first reducing its volume to the same temp., as in 100.

Fig. 47.



108. Condensed air pressure-gauges, besides being considerably affected by the temperature, have also the great objection, that as the pressure increases, and it in many cases becomes important to estimate it with increased accuracy, the divisions of the scale, corresponding to the same increase in pressure, diminish very rapidly in size, and thus become less accurate. This latter may, however, be partly remedied by furnishing the gauge with two tubes, see *fig.* 47, as first contrived by Dr. J. K. Mitchell in his experiments on the liquefaction of carbonic acid. The second tube *b* is enlarged at the end which dips into the mercury, by being cemented into a short iron tube *d* of larger diameter, which forms its lower extremity and the capacity of which is such, that the mercury only enters the glass tube at *e*, when the pressure approaches that which we particularly want to measure. Thus, suppose that the mercury in *d* only reaches to *e*, when the air in *a* is compressed to $\frac{1}{8}$ its original volume, and that then the mercurial column in it is 36

inches above the level at *c*. The pressure measured will then be $9\frac{1}{5}$ Atmospheres. Deducting from this the column from *c* to *e*, the pressure on the air in the tube *b* will be exactly 9 Atmospheres. If this volume of the tube above *e* be divided into fractions, it is evident that when the enclosed air is reduced to $\frac{1}{2}$ of this volume, the pressure on it will be 18 Atmospheres, and when reduced to $\frac{1}{4}$, 36 Atmospheres; to which, of course, in order to obtain the pressure we want to measure, must be added the mercurial column beyond *e*.

109. For experiments on a small scale, as for the compression of gases in glass tubes, a capillary tube of the proper length, see *a b fig.* 48, is employed as a gauge, having no cistern.

Fig. 48.

Being closed at one end at *a*, a small column of mercury *c* is introduced into the other open end *b*, by expelling from it, by heat, the smallest possible quantity of air, and then dipping the open end into mercury, till on cooling a small quantity of this is drawn into it (38), which then confines the air remaining in the tube. The space *ac* occupied by this air is then divided as before into fractions of its own volume. When using it, the open end *b* is either cemented into a metallic socket, which is screwed on to the end of the tube in which the gases are compressed, or in some cases the whole gauge-tube may be slipped into the compression-tube, in which case no strength is required of its sides, and these may therefore be of any thinness, and the whole gauge, therefore, of miniature dimensions. If this gauge be in a horizontal position, no allowance whatever, need be made for the weight of the mercurial column *c*; and the volume of the confined air, therefore, indicates the whole tension of the gas which we want to measure.

110. Gauges for measuring high pressures are particularly required for high-pressure steam-boilers, to indicate at any time with accuracy the tension or elasticity of the steam, and thereby to warn against accidents. Such gauges are called *Steam-Gauges*, sometimes also *Manometers*, see foot-note to 91. Besides the before described pressure-gauges, many others have been constructed for steam-gauges on different principles. Thus, the principle of Bourdon's Metallic Barometer (89), was first employed for a steam-gauge, by admitting the steam into its hollow hoop-like vessel. In the same manner an accurate thermometer will indicate from the temp. of the steam, its pressure, see 138 &c. A number of steam-gauges act on the principle of letting the steam act on a metallic valve, so as to compress a spring (Spring-Gauges), or raise a known weight. These are, however, not so much for the purpose of measuring the pressure of the steam as for affording escape and safety from it, when its elasticity should exceed a certain limit, and they are therefore called *Escape* or *Safety Valves*, see 146 *fig.* 70.

Experiments to illustrate the pressure of the Atmosphere.

111. The atmospheric pressure on the surface of liquids, may be illustrated by the Fountain or Jet in Vacuo, see *fig.* 49, which consists of a closed receiver, which is furnished at its lower extremity with a stop-cock *c*, from which a jet projects into the receiver, terminating outside by a screw *s*, by which it may be attached to the air-pump. Having exhausted the receiver, it is detached from the air-pump, and the mouth of the stop-cock immersed into a vessel containing water. On opening the stop-cock the atmospheric pressure will force the water in a jet into the exhausted receiver.

Fig. 49.

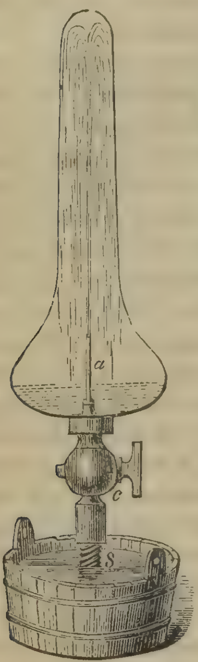


Fig. 50.

112. The Mercurial Rain, see *fig.* 50, is used to illustrate the same in connection with the porosity of certain substances such as wood, leather, &c. It consists of a receiver having inserted in the top a cup *c*, which is closed at the bottom by a stopper of wood cut across the grain, or by a piece of buckskin, and which contains mercury. On exhausting the receiver, the atmospheric pressure will force the mercury through the pores in small globules as a rain.

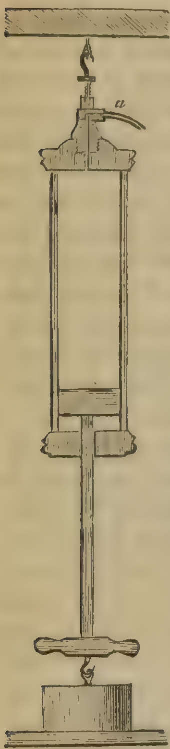
113. If a piece of thin bladder be tied over the top of a small wide-mouthed receiver, the Bladder Glass, see *fig.* 51, and the air then quickly exhausted, the atmospheric pressure will burst the bladder inward with a loud report as from an explosion.

Fig. 51.

114. The pressure on any part of an elastic fluid being equally communicated to all parts of it, it is evident that the pressure which it in return exercises on all the confining limits must be uniform, and must, therefore, also extend to the whole surface of any object immersed in it. The direction of its pressure at any point of all such surfaces, is always in the perpendicular to them at that point. The *Upward* Pressure of the atmosphere on an *under* surface, may be illustrated by

a syringe with a solid piston, see *fig.* 52. Having drawn the piston out and attached a weight to the piston-rod, suspend it, and connect the upper extremity of the barrel by the tube *a* with an exhausting air-pump. When the air is exhausted from it, the atmospheric pressure, acting perpendicularly upward on the lower surface of the piston, will force it up, thereby raising the weight attached to the piston-rod.

Fig. 52.



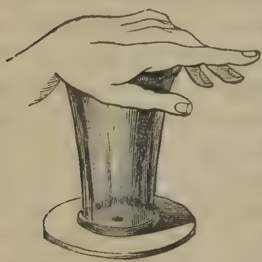
115. The same may be illustrated by the Magdeburg Hemispheres, which are two hollow hemispheres, see *a* and *b fig.* 53, having their edges ground true, so as to fit airtight together, thus forming a hollow sphere. One of them is furnished with a handle, and the other with a stop-cock and a screw *c*, by which it may be attached either to an air-pump, or to a handle *d*. If the two hemispheres be put together, and the air inside exhausted, the pressure of the atmosphere outside will force them together, so that if they be removed from the air-pump, and the handle attached, it will require a considerable force to separate them. To calculate the exact force with which they are held together, it must be remembered, that though the whole atmospheric pressure on them is equal to 15 pounds on each square inch of the whole outer surface, it is only that portion of it which acts at right angles to the plane of the joint, which holds them together. Thus, if the radius of the sphere be 2 inches, the plane surface of the circular joint ($r^2 \pi$) will be $= 2^2 \times 3\frac{1}{7} = 12\frac{4}{7}$ square inches, and the pressure on it, therefore, $12\frac{4}{7} \times 15$ lbs. $= 188\frac{4}{7}$ lbs. To pull them apart, this force must, therefore, be applied from each side. They have received their name from the fact, that they were first contrived by Otto von Guericke, Burgomaster of Magdeburg, a town in Germany, who in 1650 had invented the Air-Pump. To illustrate the Atmospheric pressure, he exhibited, in 1654 at Regensburg, to the Emperor Charles V, in presence of the Imperial Diet, a pair of these of about two feet in diameter, to which twenty-four horses were attached, without their being able to separate them.

Fig. 53.

116. The external surface of the human body being about 2000 square inches, it is evident that it must be exposed to a pressure from the atmosphere, of about 30.000 lbs., or nearly 14 tons. That

this pressure does not force in the Abdominal and Thoracic cavities of the body, is prevented by the access of the atmosphere to them, by which the external and internal pressures are counteracted. The solid walls of the body forming them, are, however, subject to it; these and the internal organs are, however, prevented from being crushed by it on account of the uniformity of the pressure, by which the particles, being pressed equally on all sides, have no tendency to change their relative position, crushing being merely produced by an unequal pressure. This is also the reason why we are not conscious of its existence. It may, however, easily be made manifest by removing the pressure from any part of the body, for instance, by placing the hand over the mouth of a small receiver, see *fig.* 54, and exhausting the air from within it; the pressure on the opposite side of the hand will then force it against the edge of the receiver and cause those parts, from which the pressure is removed, to bulge into it. The operation of cupping depends on this same, for if small cuts be previously made through the skin, the blood will be forced out through them by the pressure on the rest of the body. In such places, however, of the body, where the parts are not soft or permeable to fluids, this pressure is used by nature to sustain and keep together its different parts, without calling into requisition for this purpose the power of the muscles. Thus all the movable joints of the body are kept together by the articulating surfaces of the bones being surrounded by an air-tight ligament, so that they may slide freely over each other, but cannot be separated without producing a vacuum, and are thus forced together by the atmospheric pressure, amounting, for instance, on the knee-joint to upwards of 100 lbs. By actual experiment, by dissecting away from the hip-joint every thing excepting the capsular ligament, and suspending it under a pneumatic receiver with a weight attached to the thigh-bone, this has been found to drop out of the socket, on exhausting the air from the receiver, but to return again into it, on re-admitting the air The excessive fatigue experienced in ascending high mountains, has been ascribed to the diminution of the atmospheric pressure, by which the weight of the limbs has to be in part supported by the muscles, instead of by the atmospheric pressure alone.

Fig. 54.



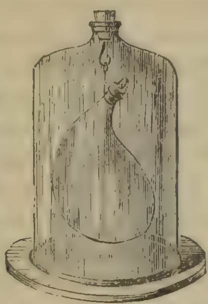
Experiments to illustrate the Expansibility, Elasticity and Compressibility of Atmospheric Air.

117. Expansibility and Elasticity of gases both depend on the same

repulsive action between the atoms, which we have called negative cohesion (12), and which causes them to have a constant tendency to extend their volume and thereby to exercise a certain pressure on the confining limits, which these must return, in order to restrain them; and as soon as this restraining pressure is diminished or ceases, it causes them actually to extend their volume. They are therefore in fact the same property, but the word elasticity is only applied to their expansive force after a previous diminution of their volume, by an increase of the pressure of the confining limits, while for their expansive force under the ordinary atmospheric pressure, or after its diminution, the word *tension* is generally used.

Fig. 55.

Fig. 56.



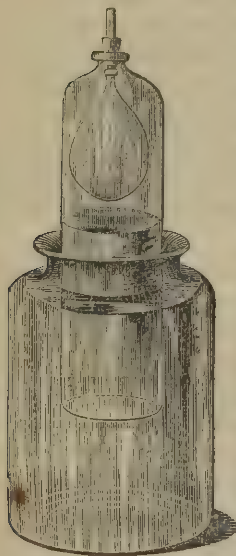
118. The Expansibility of atmospheric air is illustrated by forcing the greater portion of the air out of a sound bladder or small gum-bag by compression, and then closing the orifice by tying it firmly with a string. Place it under a receiver as in *fig.* 55. As soon as the air is exhausted from the receiver outside the bladder, the small quantity of air contained inside it will expand, and swell the bladder out, as seen in *fig.* 56. When the air is again admitted into the receiver, the bladder will collapse to its former dimensions. The same experiment will often succeed with dried and shrivelled fruit, as raisins, which, if the skin be sound, will, in a similar manner, be blown out to their original fullness by the small quantity of air which they contain.

Fig. 57.

119. *Mechanism of Respiration.* It is by a similar contrivance that air is made to enter into the lungs by respiration. The lungs may be considered as two membranous bags, only divided into a number of smaller compartments or cells, but all communicating with each other by the bronchial ramifications, through which the air may enter into them by way of the mouth and the windpipe; the whole apparatus being suspended in the cavity of the chest, as may be represented by the bladder *a fig.* 57,

attached to the pipe *b* and fixed in the receiver *h*. The *expiration* is effected by diminishing the cavity of the chest by the contraction of the ribs and the raising of the diaphragm, by which the air, in consequence of its elasticity, is forced out through the windpipe by compression. This may be imitated by blowing the bladder out through the pipe *b* and closing this with the finger, until the mouth of the receiver be immersed into a vessel *e e*, with water. On removing the finger and depressing the receiver further, the air will be forced out through the pipe *b*, as represented in *fig.* 57. The *inspiration*, on the contrary, is effected by enlarging the cavity of the chest by expanding the ribs and flattening the diaphragm, by which a vacuous space is produced between the inside of the chest and the membrane of the lungs, by which the air, in virtue of its expansibility, will enter and inflate them. This operation may be imitated with the above apparatus by gradually drawing the receiver *h* again out of the water, thereby enlarging its capacity and producing a partial vacuum. The air then enters by its expansibility through the pipe *b* and inflates the bladder as in *fig.* 58.

Fig. 58.

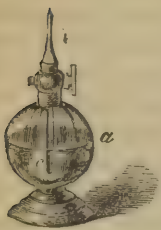


120. Common water freshly drawn always contains more or less air in solution (55). When the pressure is removed from its surface by placing it in a tumbler under a receiver and exhausting the air, the expansibility of the dissolved air will overcome the adhesion, by which it is kept in solution, and most of it will appear as small bubbles on the sides of the vessel and escape through the water.

121. Place a piece of charcoal or any other porous body in a tumbler filled with water, and this under a receiver, and exhaust the air from the latter. The air contained in the pores of the charcoal will expand and escape in bubbles through the water. On readmitting the air, the atmospheric pressure will force the water into the pores, which thus will become filled with water instead of air. This method is often employed to fill the pores of other porous bodies with water. If the pores of wood be filled in this manner with water instead of air, it will become water-logged and incapable of floating.

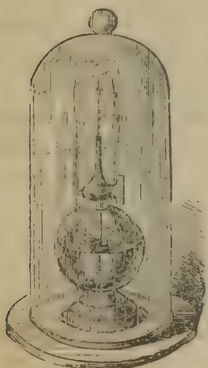
122. Hero's Ball is an apparatus used to illustrate the compressibility, elasticity and expansibility of atmospheric air. It consists of a strong,

Fig. 59.



generally spherical vessel, *a fig.* 59, having a tube inserted at the top, reaching nearly, though not quite, to the bottom, and furnished outside with a stop-cock and screw for attaching a jet *i*. A quantity of water sufficient to close the end *c* of this tube, is introduced into the vessel, either by unscrewing the tube, or by removing a portion of the air from it by suction, and then, after having inverted it and immersed the jet of the tube into water, opening the stop-cock, when the atmospheric pressure will force in a sufficient quantity of the latter (111). Remove then the jet and attach to it a condensing syringe (41). By every stroke of the piston, the air forced into the vessel will be seen to bubble through the water. Having closed the stop-cock, remove the condenser and replace the jet. On turning the stop-cock, the elasticity of the compressed air will force the water out in a jet. Having replenished, if necessary, the vessel with water, place it under a receiver and exhaust the air, see *fig.* 60. By thus removing the pressure of the atmosphere on the water inside the jet, the expansibility of the atmospheric air enclosed in the vessel will force the water out in a jet. Hero's ball is so called from its inventor, who lived in Alexandria, and described this apparatus about one hundred and twenty years before the Christian era.

Fig. 60.



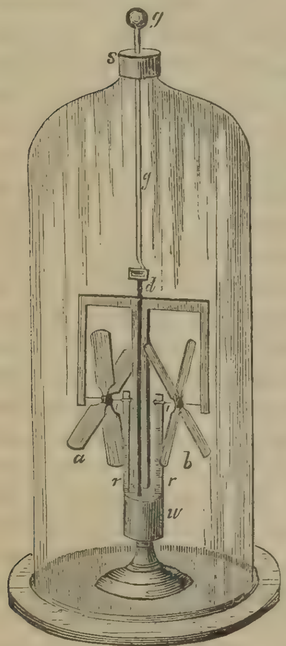
123. Contrivances acting on the same principle as Hero's ball, and called Air-Chambers, are attached to most hydraulic engines, such as the Fire Engine and the Hydraulic Ram, in order to convert the intermitting jet of these into a continuous. The air-chamber consists of a strong, more or less spherical vessel of metal, at the bottom of which the water is forced in through a valve faster than it issues from the jet, which may either pass from near the bottom through the top, as in Hero's ball, or, as is more common, from the side near the bottom. The air enclosed in the chamber is thus compressed and, by its elasticity, forces the water out in a constant stream.

Impact and Inertia of Gases.

124. Gases, like all other matter, possess *Inertia*; hence the atmosphere offers a resistance to all bodies moving in it, because these have to impart

to it by *impact* some of their motion, in order to move it out of their way. For this reason, bodies which present a large surface, lose their motion sooner than those which present a smaller, or one of a more favourable shape. In the same manner, specifically light bodies lose their motion sooner than heavy bodies, which within the same space contain more moving matter and, therefore, more motion. This may be illustrated by the Windmill experiment, which is performed by an apparatus, see *fig.* 61, having two axes *i i*, perfectly alike, and furnished with small pinions, that are worked by two perfectly similar racks *r r*, attached to the same weight *w*, so that the latter by its descent imparts exactly the same velocity to them both. At right angles to each of the axes *i i*, are attached four perfectly similar wings, which may be turned so as to present either their broad surface or their edge to the air, when the axes revolve. Place first the wings of both axes, so as to present the broad surface to the air, when revolving. Let then the weight drop so as to impart to them both the same velocity. They will both stop at the same time, and soon, on account of the resistance of the air. Turn then the wings of one axis so as to present the edges to the air, and start them again by the descent of the weight. The one with the wings turned edgeways will then continue its motion much longer than the other. But if the apparatus be placed under an exhausted receiver, and the weight again made to descend by the rod *g g*, passing through a stuffing-box *s* at the top of the receiver, both axes will be found to continue their motion equally long in the vacuum, although the wings of the one are turned differently from those of the other.

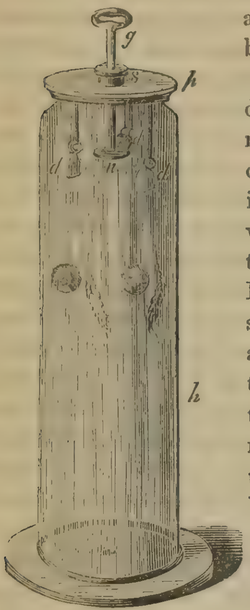
Fig. 61.



125. The resistance of the air by its inertia, is the cause why specifically lighter bodies fall in the atmosphere slower, than heavier. In a vacuum all bodies fall equally fast. This may be illustrated by the Feather and Guinea experiment, *fig.* 62, which is performed by a tall receiver *h*, containing several drop-stages *d d d*, on one of which is placed a gold-piece, and on another a feather. The air being exhausted, these are allowed to begin their descent at the same time, by allowing the stages to drop simultane-

ously by the rod *g*, passing through the stuffing-box *s*. If the air is well exhausted, they will both reach the bottom at the same time, showing that it is the resistance of the air, which causes the feather and specifically lighter bodies in general to fall slower than heavier ones.

Fig. 62.



126. The resistance on a sphere of 5 inches diameter, falling through the air, has been estimated to be 1.211 oz., when it acquires the velocity of 30 feet per second. But this resistance is increased in a much greater ratio than the velocity of the moving body, it being proportional to the squares of the velocities (See under Stereo-Dynamics). For this reason rain-drops, hail-stones, and all kinds of projectiles, such as musket and cannon balls, have all a maximum velocity in the air, which they cannot exceed. But the larger their size, or the greater the specific gravity of the material of which they are made, the greater is the velocity that can be given to them. Thus, a bullet of lead is capable of a greater velocity than one of iron. The flight of birds depends on this same increase in the resistance of the air, the motion of their wings being performed, in one direction, both with greater surface and with greater velocity, than in the other.

127. Air which thus receives motion by impact or otherwise, will by the same property of inertia continue its motion, on which the operations of fanning and blowing depend, until it in its turn is checked by some other cause; for instance, by striking against other air, or against immovable objects on the earth. The performance of windmills and the sailing of ships depend on motion received by impact from moving masses of air, which constitute winds. The power of winds increases in the same augmented ratio of the squares of their velocities, which are stated to be as follows:

	Vel. in miles per hour.	Vel. in ft. per second.	Inch. of water supported.	Pressure on a square ft. in lbs. Avoir d.p.
Gentle breeze. . . .	3.25	4.77	0.01	0.83 oz.
Pleasant breeze. . .	6.5	9.53	0.04	3.33 "
High wind.	16.25	23.83	0.25	1 lb. 5 oz.
Storm or gale. . . .	32.5	47.66	1.	5 " 3 "
Great storm. . . .	56.29	82.56	3.	15 " 9 "
Hurricane. . . .	79.61	116.76	6.	31 " 3 "
Tremendous hurricane. . .	97.5	143.00	9.	46 " 12 "

128. The direction of the wind is generally ascertained by the *vane*, but when feeble, by a suspended silk ribbon, or an ascending column of smoke; and sometimes also by the cold experienced on the finger, when moistened and held up to the air. The force of winds is estimated by instruments called *Anemometers*, the best of which are constructed on the principle of the pressure-gauge (106) *fig.* 45, being made of large diameter and containing water instead of mercury, having also the limb, acted on, horizontal, so as to turn it against the wind. But those generally adopted as the most convenient in meteorological observatories, are made on the principle of spring-gauges, exposing a surface of a known area to the action of the wind, the pressure on it being estimated by the compression of springs. Such has been made self-registering by Osler (L. & E. Phil. Mag. vol. xi. p. 476), so that, being connected with a vane, it will note by a pencil both the direction and the force of the wind for every moment.

129. When a gas is allowed to escape from a confining vessel through a small or *capillary orifice* in a thin plate into a vacuum, the velocity with which it issues remains the same; for, as the density and consequent elasticity or propelling force of the gas decreases, its specific gravity, and consequently also the propelled quantity, decreases in the same ratio, so that in the same time the same volume of gas always passes out, but of course of constantly diminishing density.

If a gas be allowed to flow through a similar small orifice, but from a vessel in which it is kept under a constant pressure (see gasometers), it will be found that the velocity with which it flows out increases rapidly, as the space into which it flows is rendered more and more vacuous, until the tension of the remaining air is only about $\frac{1}{3}$ Atm. (10 inches of mercury), after which further exhaustion will not be found to increase the velocity in the same proportion, and when the state of rarefaction reaches $\frac{1}{30}$th (1 inch of mercury, see 105), all further exhaustion seems scarcely to affect the velocity, if the pressure on the gas be 1 Atmosphere. In this manner, in 1000 seconds, 60 cub. inches (15148 fluid-grain measures) of dry atmospheric air, have been found to flow into such a vacuum through an orifice in a platinum foil of $\frac{1}{300}$th of an inch in diameter. The times which the same volumes of different gases require for their passage into such a vacuum, have been found to vary so as to be proportional to the square roots of their specific gravities, and their velocities, therefore, under the same circumstances, to be inversely proportional to these numbers. Mixtures of gases ought to have a mean rate of their constituent gases; from which rule, however, some, as hydrogen and carburetted hydrogen, have been found to make a remarkable exception, their rate being under such circumstances diminished considerably beyond what it should be.

Thus, only $1\frac{1}{2}$ per cent. of air or of oxygen, added to hydrogen, was found by Graham to retard its passage very perceptibly, and at least 3 times more than it ought, by calculation.

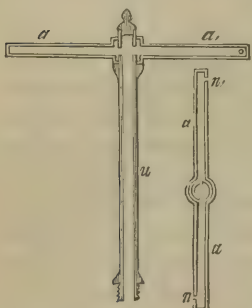
130. If, however, instead of a capillary orifice in a thin plate, a *capillary tube* of the same diameter be substituted, a very great change takes place in the above rates, the velocities decreasing rapidly, as the orifice is elongated into a tube, with the first additions, but becoming gradually less affected, and after a certain length, they remain constant for any further increase in the length of the tube. By a comparison of these ultimate velocities for different gases, it is found that the ratios between them remain the same for a considerable range of pressures (from 1 to $\frac{1}{10}$th Atm.), but that these ratios are very different from those between their velocities through capillary orifices. In some cases they approach to the ratios of their different densities, but not uniformly so. Hydrogen and carburetted hydrogen suffer also in this case, by admixture of other gases, a considerable retardation over the mean of their mixture. And even for the same gas, the velocity is found to change, becoming greater as the density of the gas is increased, so that the higher the barometric pressure on it, in the less time will the same volume of gas escape. Graham considers this a proof that the effect cannot be ascribed to friction, and he therefore distinguishes the flow of gases into a vacuum through capillary tubes, from their flow into the same through capillary orifices, designating the latter by the name of *Effusion*, while their flow through capillary tubes he calls *Transpiration*. When the space into which the gases escape, instead of being kept vacuous, is allowed to become filled with the gas, the velocities decrease slowly, while the tension of the gas increases from 1 to 10 inches, after which, however, the decrease is very rapid (Graham's Chemistry, p. 86).

131. When gases issue under pressure *into the Atmosphere*, they seem also to obey the same law that, for different gases, their relative velocities under the same pressure are inversely as the square roots of their specific gravities. For the same gas, its velocities under different pressures are as the square roots of these pressures. Thus, according to Fyfe (Edinb. New Phil. Journ., 1848, vol. xlv.), in 1 hour, 0.927 cub. foot of common lighting gas (carburetted hydrogen), of spec. gr. 0.6026 (ref. to 60° as stand.), will pass out through a jet formed of a circular orifice of $\frac{1}{40}$ inch in diam. under a pressure of $\frac{117}{100}$ inch of water (burning with a flame 5 inch. high). Of a gas of 0.500 sp. gr., 1.118 cub. foot will pass out of the same jet in the same time under a pressure of $\frac{170}{100}$ inch of water.

132. When a gas is allowed to escape under pressure from an orifice in one side of a vessel, no pressure can of course be exercised by the gas on this orifice, to counteract its corresponding pressure on an equal surface

on the opposite side of the vessel, hence this pressure must produce a tendency in the vessel to move in the opposite direction of that in which the gas flows out. This may be seen illustrated in the revolving gas-lights, seen in shop-windows in cities. In these the gas is made to enter into two lateral branches, see a and a_1 *fig.* 63, which are capable of revolving,

Fig. 63.

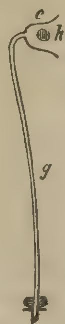


their revolving motion being produced by the gas escaping near the end on one side, while no corresponding orifice or jet exists on the opposite side, as seen in the horizontal section at n and n_1. Instead of an orifice on the side of the lateral branch near its end, the same effect is produced by bending sideways the end itself, this forming the jet.

133. If a thin plate of metal or pasteboard, b *fig.* 64, be perforated at its middle, and fastened by sealing-wax or otherwise at right angles to the end of a glass tube a, so that the aperture of the plate is directly over the bore of the tube, and another card or piece of stiff paper c be laid over the opening, having a pin d stuck through it, so as to prevent its *sliding* off, it will be impossible to force it off by blowing through the tube. On the contrary, if the apparatus be inverted, so that the paper is lowermost, blowing through the tube will prevent it from falling down, and the greater the blast, the greater will be the force by which it is held up. This experiment is called the Pneumatic Paradox. The cause of this is, that as the air from the tube spreads out when escaping between the plate and the paper, it can only separate them to a certain distance (about $\frac{1}{10}$ inch), since pushing them apart beyond

Fig. 64.

Fig. 65.



this, would cause its density to become less than that of the atmospheric air on the other side of the paper, and thus produce a partial vacuum between them. That it is the atmospheric pressure, which prevents the plate and the paper from being separated, can be proved by furnishing the other end of the tube with a screw s, and attaching it to the air-pump plate, placing over it a receiver with a stuffing-box and sliding rod, by which the paper may be held up by a loop fastened to it, till the air is exhausted, and then let down on the plate. On readmitting the air suddenly through the tube, the paper is blown off. *Fig.* 65

exhibits another modification of this experiment, the tube terminating in a bowl *c*. By blowing through the tube *g*, a ball *h* of cork or any other light material, will remain suspended, instead of falling or being blown out.

We will now give a separate consideration to the class of gases (45) which are called

VAPORS.

134. Many liquids and solids, *when their limit is towards a vacuum or towards a gas*, are capable of passing wholly or in part into the gaseous form, and of spreading in this state over the vacuum or through the gas. Such liquids and solids are said to be volatile, while those which are not capable of assuming the gaseous state (as oils), or owing to other circumstances, cannot be made to assume it (as platinum), are said to be fixed. The gases thus formed are called *vapors*. This conversion into vapors (vaporization) may take place either only from the free surface, which limits them towards the vacuum or the gas, in which case it is called Evaporation, or if the substance be a liquid, the conversion into vapors may also take place below the free surface, the vapors escaping as bubbles through the liquid and agitating it, in which case it is called Ebullition or Boiling.

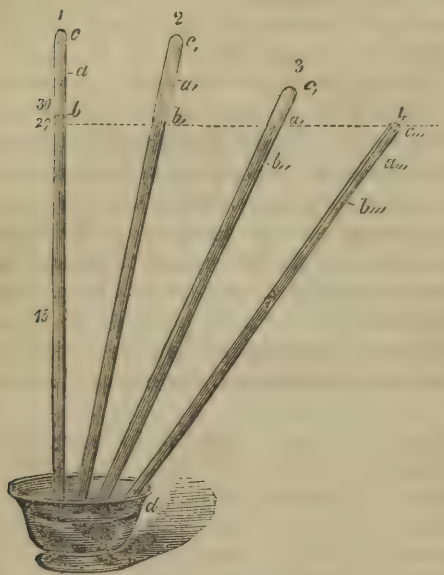
135. All vapors, being true gases, are, therefore, perfectly transparent; and, when colorless, as invisible while vapors, as all other gases, until they again assume the liquid or solid state, and at that moment again cease to be vapors. It is, therefore, a popular error to apply the word steam, by which we understand vapor of water, to the smoke or cloud formed by the particles of liquid water, into which the steam again condenses at a short distance from a steam-pipe, when escaping into the atmosphere. Near the pipe, where it is yet real steam or vapor, it is as invisible as the rest of the atmosphere. Even vapors of perfectly opaque bodies are transparent and in many cases, such as that of mercury, also perfectly colorless. In other cases, although always transparent, they may possess color. Thus, vapor of sulphur is yellow, and vapor of Iodine is of a beautiful violet color.

Formations of vapors in a vacuum.

136. To illustrate the formation of vapors from volatile substances, when limited towards a vacuum, we may employ a Torricellian Tube (60), inverted in a large cup of mercury, see 1 *fig*. 66, and furnished with an accurate scale to measure the height of the mercurial column. This column, which is supported by the atmospheric pressure, we will suppose to be exactly 30 inches. If we now introduce, through the mercury in the cup *d*, the smallest possible quantity of water into the tube 1, it

will rise to the top of the mercury at 30, and thus present an upper or free surface towards the Torricellian Vacuum. It will then in a short time be found to disappear as water, being converted into vapor, the presence of which as a gas in the vacuum is indicated by its property of expansibility, that is, its spreading over the vacuum with a certain force, until it is resisted by the limits of the latter, viz. the sides of the tube and the top of the mercury at 30, thus causing a certain uniform pressure on them all, called its *tension*, and by which the mercury becomes slightly depressed below its former level at 30. By introducing additional small quantities of water, we shall find that the same continues, the water disappearing as liquid, and the mercury becoming more depressed, until at last no more water is found to disappear, and no more depression occurs, however much water we may introduce, provided the temperature remains the same. Thus, if the experiment be performed, when the stand of the mercury is 30 inches and the temperature 59° Fah., this depression will stop at ½ inch at *b*, see tube 1 *fig*. 66, or when the mercury has a height of 29½ inches. If on the contrary, the temperature be raised, more liquid will again disappear, more vapor be formed, and the depression of the mercury become greater, till at last, when it has reached a certain point, it again becomes stationary. If the temperature be raised to 79°, this will occur when the depression becomes 1 inch, or when the height of the mercurial column is 29 inches, after which the depression does not increase any further, as long as the temperature remains the same; and so on. We conclude from this, that the formation of vapors from volatile liquids in a vacuum has a limit, which depends on the temperature, so that for every temperature, there is a certain greatest or *maximum* quantity of vapor which can be taken up, with a corresponding *maximum tension*, beyond which no more can be taken up.

Fig 66.



137. An otherwise vacuous space may therefore, at a certain temperature, contain *less* than this maximum quantity, if there be no more liquid present to form more vapor, but it can never contain *more*. The quantity which is present, whether it be the maximum or less, is always, for the same temperature, proportional to its tension, or the pressure which it causes on the mercury. Should the temperature not be the same, a deduction must first be made from its tension at the higher temperature of so much, as is due to the expansion of the vapor by heat by the difference in temperature (see 140 and 100). If, on the other hand, we can prove, that a space contains the maximum quantity, or, as it is termed, is filled to saturation with vapor, which may be known, for instance, by its having been sufficiently long in contact with an abundance of the liquid, then we may, from the temperature, estimate the quantity of vapor in the space, and its tension, since these will be the maximum quantity and tension, which correspond to the temperature.

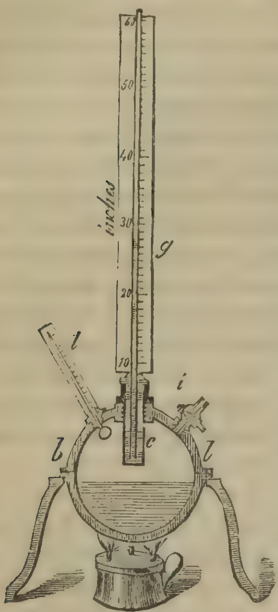
138. By experiments, the following temperatures have been found to correspond to the annexed maximum tensions and quantities of vapor of water:

Temp. Fahren.	Max. tens. in inch. of mercury.	Max. quan. in 1 cub. foot, in grains.	Temp. Fahren.	Max. tens. in Atmos.	Max quan. in 1 cub. foot, in grains.
18°.3	$\frac{1}{10}$ inch.	1.204	149°.65	$\frac{1}{4}$ Atmos.	70.640
23°.3	$\frac{1}{8}$ "	1.490	179°.08	$\frac{1}{2}$ "	134.766
32°	$\frac{18}{100}$ "	2.120	212°	1 "	256.317
40°.25	$\frac{1}{4}$ "	2.878	250°.52	2 "	484.791
59°	$\frac{1}{2}$ "	5.548	293°.72	4 "	913.951
79°.3	1 "	10.677	341°.78	8 "	1718.225
101°.4	2 "	20.512	398°.48	16 "	3209.251
126°.6	4 "	39.260			

139. From this table it will be seen, that at 212° the maximum tension of the vapor of water is equal to the atmospheric pressure, and that it therefore at that temp. will cause a depression of the mercury inside the Torricellian tube to the same level as outside. The tension or elasticity for higher temperatures than 212° cannot, therefore, be conveniently estimated in the same apparatus as described above, but we may then substitute for it the apparatus represented in *fig.* 67, consisting of a small boiler *b l*, furnished with a mercurial pressure-gauge *c g*, (106), the cistern of which, *c*, communicates by an opening with the vapor inside the boiler, so that by it we estimate the tension, while the temperature is indicated by the thermometer *t*. The boiler is also furnished with a stop-cock *i*. The boiler having been partly filled with water, the latter is made to boil by the application of heat. As soon as the escaping steam has expelled completely the atmospheric air, the stop-cock *i* is closed. The tension of

the vapor will then be found to increase rapidly, being indicated by the height of the mercurial column in the gauge, while the corresponding temperatures are indicated by the thermometer. In the experiments performed for the French Academy in 1829, by Arago and Dulong, for estimating the elasticity of steam at higher temperatures, the highest tension measured was 24 Atmospheres. The tensions were estimated by a condensed air-gauge (107), which had previously been tested by a mercurial gauge (106) to the extent of 27 Atmospheres. The tube of this latter was therefore over 68 feet high, having been ingeniously constructed and arranged in an old church-tower. Mariotte's law was thus found to be correct to the above extent (Annal. de Chim. et de Phys., 2d series, vol. xliii). The tensions below 212° have been estimated with great accuracy by Regnault (Ann. de Chim. et de Phys., 3d ser., vols. xi, xiv and xv).

Fig. 67.



A complete set of tables of the tensions of vapor of water in English inches, and the temps. in Fahr. degrees, has been computed for this work from the tables furnished by these authors, and will be found at the end of Pneumatics, in Tables VII, VIII and IX.

140. It is evident from these and the above-given table (138) of the maximum tensions and quantities of vapor, that these increase with extraordinary rapidity and in a much greater ratio than the temperatures, *when in contact with the liquid.* This is due to the *additional* vapors formed from it.* If, on the contrary, at any time, there be no liquid present, the increase in tension will only be that which follows from the expansion of the vapor by heat, which is the same as that of any other gas under the

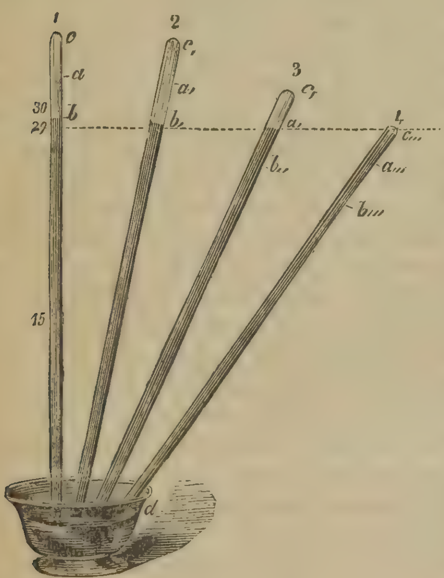
* As regards the tensions of vapors at *very high* temperatures, it would seem from some interesting experiments of Cagniard de la Tour, that they do not continue to increase in the same augmented ratio. By enclosing volatile liquids in sealed glass tubes, and exposing these to heat, he found that ether passed at 320° entirely into the state of vapor in a space scarcely double its own volume, and without exerting a pressure of more than 38 Atmos. Alcohol passed into the gaseous state at 404½°, in a space of 3 times its own volume, thereby exercising a pressure of only 139 Atmos., and water (to which a small quantity of Carbonate of Soda had been added to prevent the breaking of the tube), in a space 4 times its own volume, at about 648°.

same circumstances, or for every degree Fahrenheit 0.00203611 of its volume at 32°, or 0.00217802 of its volume at 0°.

141. Conversely, if vapors do not fill the space to saturation, as in the last-mentioned case, when heated to a higher temperature without contact with the liquid, or when allowed to spread through a vacuum in a less quantity than to fill it to saturation at the existing temperature, such vapor may again, without becoming liquid, be subjected to so much *pressure* or *cold*, as will again reduce it to the state of saturation. But as soon as the pressure becomes greater than its maximum tension at the existing temperature, it will all be reconverted into liquid; and if the temperature becomes less than that, at which its tension is the maximum, a portion of it will condense.

142. Thus, as an illustration of this in regard to *pressure*, suppose that at the temperature of 79°.3 and 30 inches barometric stand, the Torricellian vacuum *b a c fig.* 68 *tube* 1, contains vapor of only ½ inch tension,

Fig 68.



that is only ½ the maximum tension and quantity, which belong to that temperature. The level of the mercury will then of course be at 29½ inches, or at *b*. The vapor being thus only ½ the quantity that can exist in the space, it may be subjected to an additional pressure of ½ inch, or till its volume is compressed to ½ of its former volume, or into *c a*, without any condensation taking place. This increase in pressure is produced by inclining the tube, as *tube* 2 in the *fig.*, which has the effect of diminishing the Torricellian vacuum above the mercury, by which the vapor becomes more compressed, and its density and tension thereby greater, so that it depresses the mercury more, say to 29¼ inch at b_1. The compression of the vapor may thus be increased by still farther inclining the tube, without any condensation occurring, until the depression in the perpendicular height of the mercury is 1 inch, or the perpendicular height of the mercurial column 29 inches, see

tube 3, when, in consequence, the atmospheric pressure on the vapor will be 30 — 29 inches, = 1 inch of mercury. At the same time the vapor will also be compressed to the volume $c_1 a_1$, that is ½ its former volume, and its tension in consequence doubled or equal to 1 inch. The pressure on the vapor being thus equal to its maximum tension at that temperature, any farther inclination of the tube will not cause the mercury to become more depressed, but merely diminish the Torricellian space, by which as the space become diminished, the vapor in it will be compressed to liquid water, till at last, when the top of the tube reaches the level of 29 inches, see *tube* 4, no vapor will remain, all having been converted into liquid, which will appear as a drop at the very top of the tube.

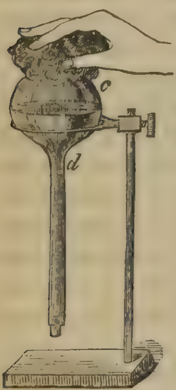
143. In the same manner, as regards *temperature*, if the tube or any other vessel containing vapor, not filling it to saturation, be subjected to *cold*, the temperature may be lowered without any condensation taking place, until it reaches that degree at which the vapor forms a maximum, after which a portion of it will be reconverted into liquid, only leaving so much vapor, as will be the maximum at the temperature to which it is cooled. Thus, as in the above case, if the temperature be 79°.3, and the tube contain vapors of only ½ inch tension, which is only ½ the maximum tension and quantity corresponding to this temperature, it may be cooled without any condensation taking place, to the temperature of 59°, this being the temperature at which its tension will be the maximum. But if then the temperature be still farther lowered to 40°, so much of it will condense, that what remains has only a tension of ¼ inch, which is the maximum at that temperature. As the condensation of a portion of the vapor gives the appearance of a dew on the sides of the vessel, the temperature at which this *begins* to take place, is called the *Dew Point.* The condensation of a portion of the vapor or its appearance as a dew, by the *slightest* increase in cold or pressure, *is the surest proof that the space is filled with vapor to a maximum or to saturation.*

144. The formation of vapors by boiling, will take place whenever the temperature of the liquid becomes so high, that the maximum tension, which corresponds to its temperature, is equal to, or greater than, the tension or pressure of the vapor on its free surface. By this the liquid will be capable of forming vapors below the free surface, which vapors generally appear as small bubbles on the surface of the containing vessel, where the liquid is in contact with it, and which bubbles force their way through the liquid, and agitate it. In a close vessel, like that of *fig.* 67, the temperature of the water may, therefore, by a very gradual heating be raised, without producing boiling, to any degree, the maximum tension of which the vessel will bear without bursting, since

by such gradual heating the formation of vapor by evaporation from the free surface, will keep pace with the maximum tension, which corresponds to the temperature of the liquid. If, however, the vessel be heated very suddenly from below, so as to raise the temperature very rapidly, boiling may be produced for a short time, till the tension of the vapor above becomes the maximum for the temperature of the liquid. Another much easier way of producing boiling on the same principle, is by suddenly diminishing the tension of the vapor on the free surface. This may be done, where the tension is greater than the atmospheric pressure, as in the apparatus *fig*. 67, by letting the vapors escape into the air by opening the stop-cock *i*, by which a violent ebullition will take place, until the temp. of the liquid is again lowered to 212°, which is the temperature which corresponds to the diminished pressure of the vapor on its surface (1 Atm).

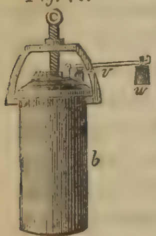
145. Another mode of diminishing the tension of the vapors, particularly if less than the atmospheric pressure, is by their condensation, absorption, or exhaustion. Thus, the production of boiling by condensation of the vapors, by applying cold to that portion of the vessel where they are contained, may be illustrated by an experiment, known under the name of the Culinary Paradox (so called because it produces boiling by cold), which consists in boiling water in a globular glass vessel with a long neck (bolt-head), till all the atmospheric air is expelled. It is then quickly closed up by a cork, while removing it from the fire, and inverted as in *fig*. 69. By applying carefully, so as to prevent its breaking, a piece of ice or a sponge moistened with cold water to the top at *c*, where the vapors are contained, these are condensed, and the water will then begin to boil violently.

Fig. 69.



146. Strong vessels for heating liquids to a high temperature, furnished with a safety-valve to regulate the highest temperature of the liquid, and consequent pressure of the vapor, affording the latter an escape, if exceeding a certain limit, are known under the name of Papin's Digestor, see *fig*. 70. Such have been applied to different purposes by the greater solvent power, acquired by liquids at temperatures higher than their boiling point in open air; for instance for the extraction of gelatine from bones by water, or the solution of resinous substances for varnishes by alcohol or oil of turpentine.

Fig. 70.



147. From the table given in 138 it will be seen, that

water continues to emit vapors many degrees below its freezing point, and that, therefore, even ice is volatile. The question therefore arises: do volatile substances continue to emit vapors at all temperatures, however low, although of course in a continually diminishing ratio, so that for those substances which are volatile to a perceptible degree only at higher temperatures, their evaporation becomes at last inappreciable, and, therefore, imperceptible at lower temperatures? or do they exhibit at a certain temperature a theoretical or absolute stop to the further formation of vapors? According to the experiments of Faraday, mercury has been found to begin to emit a very small but perceptible quantity of vapor in summer between 60° and 80°; but in winter the formation of not even a trace could be detected by the most delicate tests. It seems therefore probable, that volatile substances cease all at once to emit vapors, and that this point will be arrived at, when their expansive or evaporative power becomes so small, that it is counteracted or overcome by the forces of cohesion and gravity (compare also 27).

148. The maximum quantities and corresponding maximum tensions of other volatile substances for the same temperatures, are different from those of water, being greater for the same temperature, the more volatile they are. An idea of their relative volatility may be obtained by referring to their boiling-point in air (see 154), which indicates the temperature at which their maximum tension is the same as that of water at 212°. The lower their boiling point, of course the greater is their volatility. But the ratio of the increase of the tension of their vapor, to the increase in the temperature, is somewhat different for the different substances. Thus the boiling-point of mercury is 662°, and the tension of its vapor at that temperature, therefore, 30 inches, or 1 Atm. For lower temperatures Regnault obtained the following maximum tensions of its vapor in a vacuum:

Temperature	212°.2	144°.93	120°.47	77°.7
Tension	0.160 in.	0.0072 in.	0.0034 in.	0.0013 in.

149. It will be evident from the foregoing, that the conversion of volatile substances into vapors in a vacuum is facilitated: 1st, by an increase in the temperature, and, 2d, by the removal of the vapor as fast as it is formed. The latter may be effected either by *condensation*, by the external application of cold to a different part of the vacuum at a distance from the liquid; by *absorption*, by placing in a different part of the vacuum a substance, that by its adhesion or chemical affinity will attract and thereby remove the vapors; or in some cases by *exhaustion* of the vapor by an air-pump.

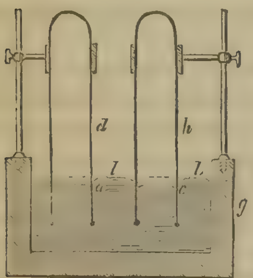
150. In the same manner as the removal of the atmospheric pressure

will cause the expansibility of gases to overcome their adhesion to solids (121) or liquids (120), so the placing of volatile liquids in a vacuum will have the same effect, causing their expansive or evaporative power to overcome their adhesion or even feeble chemical affinities. Hence in chemistry, desiccation or drying, evaporation and boiling, and the expulsion of chemically combined water, are often effected or assisted by placing such substances with suitable arrangements in a vacuum.

Formation of vapors in a gas.

151. To illustrate the formation of vapors from liquids, when their limit is towards a gas, we may use several receivers, see *d* and *h* *fig.* 71, filled with different gases, such as atmospheric air and hydrogen,

Fig. 71.



and placed in a pneumatic cistern *g*, containing mercury, one side of which should be of glass, so to enable us to observe the mercurial levels inside. The receivers having been adjusted so that the mercury has the same level outside and inside, the gases exercise themselves the same tension on the mercury, and are of course under the same pressure, as the air outside, that is, one Atmosphere. If we now introduce into those two receivers, as before into the Torricellian vacuum (136), a small quantity of water, we shall find that it in the same manner disappears as liquid, being converted into vapor, spreading through the gas as such, and indicating its presence there by its tension, which causes the mercury to be depressed lower inside than outside, and thus, like any other gas, adding its volume and tension to the gas to which it mixed. By introducing additional quantities of water, the same will be repeated until the depression of the mercury has reached a certain point, when it will increase no more, the water remaining liquid and no more vapor being formed, however much water be introduced, provided the temperature remain the same. If, however, this be raised, more vapor will be formed, and the depression increased, till it again becomes stationary. This proves that the formation of vapor in a gas from a liquid, has a limit as in a vacuum, beyond which no more can be taken up, so that for a certain temperature there may be less, but there cannot be more, than this maximum quantity with a corresponding maximum tension. As the vapor in every case adds its tension to that of the gas, its quantity must therefore always be, making allowance for differences in temperature, proportional to the additional

tension acquired by the gas. What, however, is very extraordinary is, that *the maximum quantities* for the same temperatures, which can exist *in the different gases, are the same for them all, and exactly the same as in a vacuum.*

152. Dr. Dalton of England, who first discovered this law, connecting it with the fact that gases are not capable of resisting each other's expansibility, or of limiting each other (52), expressed it in this manner, that gases are to each other as vacua. There is, however, this difference between the formation of vapor in a vacuum and in gases, that while in a vacuum it takes place very rapidly, and the maximum quantity is attained soon, it is much slower in gases, requiring much longer time to attain the maximum, and the times varying for different gases, being shorter for those the specific gravities of which are less. The relative times for obtaining the maximum quantity of vapor in different gases, have been found, under otherwise similar circumstances, to be inversely proportional to the square roots of their specific gravities, which is the same law as for diffusion. This seems to indicate that the formation of vapor in a gas depends on the same cause as the penetration of gases through each other by diffusion, and therefore depends not only on their own expansibility, but also on the attraction of the atoms of the gases toward each other, or adhesion. Regnault has also found that the tension of vapor of water in atmospheric air is two or three per cent. less than in a vacuum at the same temperature, and that its density also has a slight deviation, but it is uncertain whether this apparent deviation may not be ascribed to other causes.

153. Boiling depends here, as in a vacuum, on the same principle, and will occur whenever the maximum tension corresponding to the temperature of the liquid is greater than that of the pressure of the gas and the vapor on its surface. It will thus be seen that the boiling of water in the atmosphere must occur at 212°, since at this temperature the maximum tension is equal to the pressure of the atmospheric air on its surface, and its vapors, therefore, are capable of sustaining themselves against this pressure, so that by forcing their way as bubbles through the water, they cause the agitation, which we call boiling in open air. The singing or hissing noise, generally called simmering, which is heard just before boiling, is caused by the water above not having yet acquired the full temperature of 212°, by which the vapors formed at this temperature below, in contact with the vessel, are again condensed by contact with the water.

154. The more volatile substances are, the greater is the tension or elastic force of their vapor at the same temperature, and the lower is therefore their boiling-point in open air. The following table exhibits the boil-

ing-point in open air of different substances at the mean barometric pressure of the atmosphere of 29.918 inches:

	Boiling-Point.
Chlorohydric or Muriatic Ether	52°
Ether (a liquid, frequently called Sulphuric Ether)	96°
Alcohol (Sp. Gr. 0.798)	173°
Water	212°
Oil of Turpentine	314°
Oil of Vitriol (Sp. Gr. 1.845)	620°
Mercury	662°

155. If, however, the atmospheric pressure on the surface of the water or other volatile liquids be increased, it will require a higher temperature to produce boiling; and if it, on the contrary, be decreased, boiling will take place at a lower temperature. If, therefore, water of less temperature than 212°, or even of ordinary high temperatures (70° to 80°) be placed under a receiver, and the air quickly exhausted, it will begin to boil.

156. As water emits vapors of a certain tension at all temperatures, it might be supposed that by removing all pressure from its surface, it could be made to boil at any temperature. This is, however, not the case, as it cannot be made to boil, even in a perfect vacuum, below the temperature of 67°. The reason of this is, that although at this temperature it is yet capable of furnishing vapor of a tension of more than ½ inch of mercury, this tension is not sufficient to overcome the pressure caused by the weight of the layer of liquid above it, or to break the cohesion of its particles. Other volatile liquids have a similar limit or lowest temperature, below which they cannot be made to boil in a vacuum, being approximately the same number, or 145° below their boiling-point in open air.

157. The principle, that the temperature at which pure water boils depends on, and varies with the atmospheric pressure, being always that at which the maximum tension of its vapor is equal to the atmospheric pressure on its surface, is used in the construction of the Boiling-Point Barometer, described in 87.

158. From the foregoing it will be evident, that the conversion of volatile liquids into vapors in a gas in a close vessel, or in the open atmospheric air, is facilitated: 1st, by heat, and, 2d, by the removal of the vapor as fast as it is formed. This latter may be effected by *condensation*, by applying externally cold to another part of the close vessel at a distance from the liquid (Distillation); by *absorption*, by placing in a different part of the close vessel substances, which, by their adhesion or chemical affinity, will attract and thus remove the vapor; or by *displacement* of the satu-

rated air over the liquid by less saturated or perfectly dry, and, in some cases, even heated air.

159. These principles are often applied in chemistry for effecting or accelerating the drying of vessels or substances containing water. Thus, the drying of narrow-mouthed vessels, such as bottles, which even by heating requires considerable time, is effected in a few moments by removing the saturated air by suction through a tube, the other end of which is introduced to the bottom of the vessel.

Vapor of Water in the Atmosphere.

160. The atmosphere always contains Vapors of Water (26), which are formed by evaporation from the sea and the moist earth. From various causes (92), these again condense to liquid water either on the surface of the earth as dew, or in the atmosphere itself as small hollow spheres or vesicles, filled with air, which constitute fogs and clouds.

These vesicles may be observed by a lens of 1 inch focus against a dark ground. Saussure found those forming the mist on high mountains to have a diameter of $\frac{1}{4500}$ to $\frac{1}{2780}$ inch, but occasionally to be as large as a pea. A fog is a cloud resting on the earth. On the other hand, by ascending into the clouds, these appear as fogs. According to Howard the different varieties of clouds are named as follows:

Cirrus, Curl- or Feather-Cloud, composed of delicate feathery streaks or filaments, more or less straight, curly, or confused. After a spell of fine weather they are generally the first to change the blue color of the sky, and they are often the last remaining, when the weather becomes fine. They are the highest of all clouds, and have, in some cases, been estimated to have an elevation of 20,000 feet.

Cumulus, Accumulated or Heap-Cloud, forming large hemispherical masses, with a more or less horizontal base. They are often piled on each other, and when lighted by the sun, appear as mountains of snow. In hot weather they frequently appear as the heat of the day increases, and disappear again toward evening.

Cirro-Cumulus, is the name given to those small, white, generally rounded clouds, arranged in rows, mostly with the blue sky visible between them. After rainy weather, the clouds often break into these, and they give to the sky a mottled appearance (Mackerel-back sky).

Stratus, Layer-Cloud, forms a misty layer of clouds near the earth. It often forms at sunset, and again disappears after sunrise. It sometimes resolves itself into a heavy dew, at other times it rises as cumulus.

Cirro-Stratus, forms streaks or bands, but heavier than the cirrus, which often passes into it. When in the horizon it causes the beautiful colors of the sunset; but when heavy gives it the dark-red appearance, which by many is considered as the precursor of rain. When high up, it often appears as attenuated clouds, covering the sky as with a veil, but at other times it assumes a darker and more threatening aspect.

Cumulo-Stratus, consists of dense masses and layers. It is generally formed by the increase of the cumulus, extending irregularly at the top, and losing its straight base by the addition of irregular appendages hanging down from it. It is then apt to pass into the next.

Nimbus, or real rain-cloud, characterized by its uniform grey or dark appearance, with

fringed or indistinct edges, not allowing the different clouds of which it is composed to be well distinguished.

The word *Scud*, is often applied to the loose and low masses of clouds, which during a storm are seen to move with great rapidity below the other clouds, and often in a different direction from them.

When the vesicles of the clouds break and unite into solid drops, they form rain. As, in the rule, the atmosphere near the earth must always become saturated with vapors, before rain can fall, the rain-drops increase in their descent by the condensation of additional vapors on their surface, and their size therefore depends on the height of the clouds. This increase is very perceptible by measuring the quantity of rain falling at different heights in the same place. Thus, an increase in the annual amount of rain of over *one-half*, has been observed in a fall of 240 feet. The amount of rain which falls is estimated in inches, indicating the depth of the layer of water which it would form, if allowed to remain standing on the earth. The instrument used for this purpose is called the *Rain-gauge* or *Ombrometer*, and consists of a funnel, the mouth of which has a known area, and which discharges the water into a large bottle or other suitable vessel of sufficient capacity, in or from which it is measured in cubic inches. The number of cubic inches, divided by the number of square inches constituting the area of the mouth of the funnel, gives the height or depth of the water fallen. Thus, if the mouth of the gauge be circular and 7.98 inch. in diameter, each cubic inch of water will correspond to 0.02 inch of rain. Rain-gauges may also be made self-registering (Osler's). The annual amount of rain increases from higher latitudes toward the equator, varying from 13 to 126 inches. In Philadelphia (Penn. Hospital) it is 44 inches. But the number of rainy days, over which the fall of the rain is distributed, varies in the reverse order.

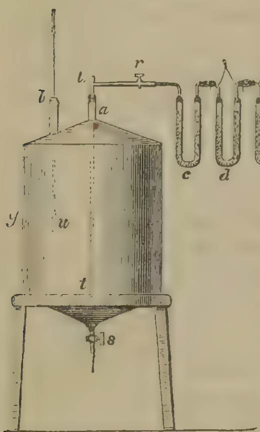
Hailstones are frozen rain-drops, their size increasing by a prolonged suspension in the atmosphere by powerful upward currents or by electricity. Snow is formed by the freezing of vapor or of the vesicles. Snow-flakes often exhibit the most beautiful starlike appearances, varying much in the form of their rays, but are always of the same form in the same snow-fall. Their form is produced by the different small crystals of which the flake is composed, arranging themselves in different manners, although always at the same angles.

161. The two most important forms in which water exists in the atmosphere, are, therefore, in the liquid state as vesicles, and in the gaseous state as vapor. Both states constitute what is *commonly* (see 162) understood by the dampness or moisture of the atmosphere. When, however, the atmosphere is perfectly transparent, the water may be considered as existing entirely in the state of vapor. But even in this state, when approaching the point of saturation, it imparts to the atmosphere a decided dampness; and by depressing the perspiration of the skin, which cannot pass off as vapor, when the air is saturated, it causes such air, if cold, to feel chilly and harsh or raw, and, when hot, sultry and oppressive. In the same degree also, as the air approaches the state of saturation, the tendency of the vapor to precipitate in the liquid state, increases, and it therefore becomes important to estimate at any time the vapor in the atmosphere, and its approach to saturation.

162. By *moisture* or *humidity*, or *absolute moisture* or *humidity*, in the *meteorological sense*, is understood the quantity of water, which exists in the atmosphere in the state of *vapor*, while by *relative mois-*

ture or *humidity*, is understood the fraction which this constitutes of the maximum quantity or of saturation for the existing temperature. Thus, a relative humidity of 0.31 means, that the atmosphere contains $\frac{31}{100}$ths of the quantity of vapor, which at the temperature in question, whatever this may be, would constitute saturation. Instead of referring the relative humidity to saturation as 1, it is often referred to it as 100, in which case the above relative humidity will be 31. It is therefore on the *relative moisture*, and not on the absolute quantity of vapor, that what is *commonly* called the *dryness* of the air depends, for if the quantity of vapor only forms a small portion of the quantity which constitutes saturation, the air will yet freely take up more vapor, and therefore appear dry. Thus the same air that in winter is called damp, will in summer, when the temperature is higher, appear dry.

Fig. 72.



163. The most accurate way of estimating the quantity of vapor in the atmosphere is by the chemical method, see *fig.* 72, which consists in passing a known volume of air though a U-shaped tube *e*, filled with pieces of pumice-stone, previously moistened with oil of vitriol, which absorbs all the vapor from it. The air is drawn very gradually through this tube by connecting it with the aspirator *g* filled with water, which latter is allowed to run out very slowly through the stop-cock *s*, and thereby draws the air through the tube *e*, to replace it. The tube *c* is also filled with pumice, moistened with oil of vitriol, but is permanently attached to the aspirator, to prevent any vapor passing from it into the tube *e*. The tube *d* is similarly filled, but serves only as a check to ascertain whether all the vapor has been absorbed by the tube *e*, and may be dispensed with. The tube *e* is weighed accurately before and after the experiment, and its increase in weight is the amount of vapor in the volume of air drawn through it by the aspirator *g*. This volume is estimated by measuring the quantity of water which it holds. A strict account must be kept of the temperature of the air during the experiment, by placing a thermometer at *f*, where it enters the tube. The aspirator is also furnished with a thermometer *b u*, and should its temperature at the end of the experiment differ from the average temperature of the air which entered, its volume

must be reduced to the same, making also a deduction for the quantity of vapor in it, and for any variation in the barometric pressure during the experiment (100). Should the state of moisture of the room in which the experiment is performed be different from that of the atmosphere, the air must be drawn in from the outside by a longer tube. Having thus obtained by weight the absolute quantity of vapor in a certain volume of the atmosphere, the relative humidity is easily obtained by dividing this obtained quantity by the maximum quantity for the same volume (168), corresponding to the observed temperature of the air; or the tension of the vapor may be calculated from the obtained weight (168) and divided by the maximum tension for the temperature of the air (164). This method allows us also to estimate the quantity of vesicular water existing in the atmosphere, since in such case the air must be saturated with vapor, and its quantity, therefore, equal to the difference between the quantity obtained by the experiment, and the maximum quantity for the temperature. It has, however, the inconvenience, that it requires longer time, considerable skill in the operator, and expensive apparatus, particularly for weighing the tube with sufficient accuracy. Other methods and instruments have therefore been contrived, which will now be described.

HYGROMETERS.

164. By *hygrometers* (from ὑγρος (*hugros*) moist, and μετρον (*metron*), measure), we understand instruments for estimating the moisture of the atmosphere. The best of these act on the principle of finding the Dew-Point, that is, the temperature at which the vapor existing in the atmosphere would be the maximum quantity or fill it to saturation. This is done by cooling a portion of it till the vapors condense as a dew (143), and then observing the exact temperature at which this begins to take place, which temperature constitutes the dew-point. As the vapor in the atmosphere is not confined, but free to contract or expand, *the maximum tension corresponding to its dew-point must be the same as its tension in the atmosphere at the existing temperature*, and will therefore bear the same ratio to the maximum tension corresponding to the temperature of the atmosphere, as its quantity bears to the maximum quantity for this same temperature. *We therefore obtain the relative humidity of the atmosphere by dividing the maximum tension, corresponding to the temperature of the Dew-Point, by the maximum tension corresponding to the temperature of the atmosphere.* For this purpose the maximum tension for every 0.2 degree Fah. from 104° to 0° will be found in Table IX, at the end of Pneum.

Thus, suppose that the

Dew-Point = 60° *Temp. of Atm.* = 85°;

we then have from Table IX,

Max. Tension for 60° = 0.518 *inch*
" " " 85° = 1.203 "

therefore: *Relative Humidity* $= \frac{0.518}{1.203} = 0.431$;

that is, the atmosphere contains $\frac{431}{1000}$ths of the quantity of vapor, which it is capable of taking up, and which would constitute saturation at its temperature of 85°. Instead of referring to saturation as 1, the relative humidity is often referred to it as 100. In the above case it would then be 43.1.

165. Conversely to find from the relative humidity and the temp. of the atmos., the tension of the vapor in it and the dew-point, we multiply the max. tens. for the temp. of the atmos., taken from Table IX, by the rel. humidity *referred to saturation as* 1, which gives us the tension of the vapor in the atmos., and as this is also the max. tension for the dew-point, the temp. which in Table IX corresponds to this tension is the dew-point.

166. To obtain the quantity of vapor in the atmosphere, either *by volume* or *by weight*, referring it to the atmospheric air itself as 1 (which if referred to it as 100, constitutes the per centage by volume or by weight), we may consider vapor of water as obeying Mariotte's law, both as regards its volume and its density in the atmosphere. To estimate, therefore, its *volume*, it must be kept in mind, that while occupying the whole volume of the atmosphere through which it is diffused (the *observed* volume), it only sustains so much of the atmospheric pressure as is equal to its own tension f, and that to obtain the *true* volume V, which it would occupy under the whole atmospheric pressure B (see 100), we have that:

$$V : \textit{Vol. of Atmos.} :: \frac{1}{B} : \frac{1}{f}$$

therefore, calling the volume of the atmosphere 1, we have

$$V = \frac{f}{B}$$

f being = the tension of the vapor, which is the same as the maximum tension for the dew-point, and B = the stand of the Bar. Thus, suppose the dew-point = 60°, and the stand of the Bar. = 29 inch., we then have from Table IX, that the max. tension for 60° = 0.518 inch, and therefore:

$$V = \frac{0.518}{29} = 0.01786;$$

that is, the volume of the vapor constitutes 0.01786 of that of the atmosphere, or it is 1.786 per cent. by volume.

167. To obtain the *weight* of the vapor in the atmosphere, referred to that of the atmosphere itself as 1, we multiply the tension of the vapor by 0.622 (Sp. grav. of Vap. Water), and divide this product by itself after

having added to it the difference between the stand of the Barometer and the tension of the vapor. Or, calling the weight of the vapor W, we have:

$$W = \frac{0.622\, f}{(B-f) + 0.622\, f}$$

f being = the tension of the vapor, which is the same as the maximum tension for the dew-point, and B = the stand of the Barometer. Thus, suppose, as in the former case, the stand of the Barometer = 29 inch. and the dew-point 60°, we then have as before, from Table IX, the maximum tension for 60° = 0.518, therefore:

$$W = \frac{0.622 \times 0.518}{(29 - 0.518) + 0.622 \times 0.518} = 0.01119;$$

that is, the weight of the vapor is 0.01119 of that of the atmosphere, or it is 1.119 per cent. by weight.

168. To obtain the *absolute weight* of the vapor *in a given volume*, for instance, *in* 1 *cubic foot of the atmosphere*, or what is the same, since this quantity is the same as if the space contained no air, *the absolute weight of* 1 *cubic foot of Vapor of Water*, we have by Mariotte's law, as stated in 166, that the densities of the vapor in the air at ordinary temperatures may be considered proportional to the pressures on it, the pressure on it at any time being the same as its tension. We know also that its expansion by heat is the same as that of other gases (140). To find, therefore, the weight of vapor in 1 cubic foot of the atmosphere, or 1 cubic foot of vapor of the tension and temperature in which it exists in the atmosphere, we proceed as directed in 100, by first reducing 1 cubic foot (considering this as the *observed* volume of vapor) to the standard pressure (29.918 inch.) and temperature (32°), and then multiply the thus-reduced volume, first, by the weight of 1 cubic foot of atmospheric air of the same standard pressure and temperature (= 563.1007 grains), and then by the specific gravity of Vapor of Water (= 0.622), so that calling the weight of the vapor in 1 cubic foot W, we have:

$$W = 1 \times \frac{f}{29.918} \times \frac{1}{1 + 0.0020361\,(t - 32°)} \times 563.1007\ grs. \times 0.622$$

$$= 11.7055\ grs. \times \frac{f}{1 + 0.0020361\,(t - 32°)},$$

f being = the tension of the vapor, which is the same as the maximum tension for the dew-point, and t = the temperature of the atmosphere, or of the vapor. Thus, suppose the dew-point = 60°, and the temperature = 85°, we then have from Table IX the maximum tension for 60° = 0.518 in., and therefore the weight of vapor in 1 cubic foot, W:

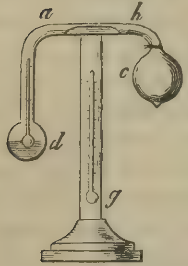
$$W = 11.7055\ grs. \times \frac{0.518}{1 + 0.0020361\,(85° - 32°)}$$

$$= 5.473\ grains.$$

By actual experiments, Regnault found that the quantities thus calculated on the above-stated supposition, that vapor of water, when diffused through air, obeys Mariotte's law, and that its tensions and densities are the same as in the vacuum, were only about 1 per cent. greater than those obtained by actual weighing of the vapor (compare 152).

Hygrometers giving the Dew-Point.

Fig. 73.



169. *Daniell's Hygrometer.*—It consists of a moderately wide glass tube, see *ah fig.* 73, blown out at its two extremities into bulbs, and bent twice at right angles. One bulb is partly filled with liquid ether, while the rest of the apparatus is freed from atmospheric air, but contains, of course, vapor of ether. The bulb *d* containing the ether, has a thermometer inside; while the other bulb *c* is covered with thin muslin. To use it, we first pour ether, drop by drop, on the bulb *c*, which ether, by its evaporation, produces cold (see Latent Heat under Thermics), and thereby condenses the vapor inside. By this, the tension or pressure of the vapor on the liquid ether in the other bulb *d* is removed, and the ether in it thereby begins to boil, or evaporate very rapidly (145). The temperature of the remaining ether in the bulb is thus lowered, and thereby that of the bulb itself and the atmosphere surrounding the bulb on the outside; till at last the vapor of the atmos. forms a maximum, and then begins to condense on the outside of the bulb as a dew. At this moment the temperature of the bulb is observed by the thermometer inside, and this gives the temperature of the dew-point of the atmosphere. As this is apt to have been observed too low, the thermometer should also be read off, when the dew again disappears, and the average between the two observations, taken, as the true dew-point. Generally, the stand *g* on which this instrument is supported, is furnished with a thermometer, by which the temperature of the atmosphere at the same time, is ascertained.

Daniell was the first to furnish us with a practical hygrometer on a true scientific principle—that of finding the dew-point. It has, however, this inconvenience, that, as the cooling of the ether takes place from the upper surface and is not readily communicated to the layers below, the thermometer is apt not to indicate accurately the temperature at which the dew deposits. When the dew-point is very low, it is also difficult to manage, and if not observed at the moment when the first dew appears, which may easily escape notice, it gives the dew-point too low, and the experiment must be repeated. To facilitate the observation of the first dew, the bulb

is often made of dark glass, or it is furnished with a gilt band or zone around it.

170. *Bache's Hygrometer*, see *fig*. 74, consists of a horizontal bar or tube a c, of steel or brass, kept bright on the outside, the one end of which is inserted in a box b, containing ice, or ice and salt, by which its temperature is made to decrease gradually from the free end a, which has the temperature of the atmosphere, to the end c inserted in the box. At the point, which has the temperature of the dew-point of the atmosphere, the moisture will begin to precipitate and form a very distinct limit, from which its amount increases more and more toward the cooled end. To ascertain accurately the temperature of the bar, where the moisture begins to precipitate, and which indicates the dew-point, that portion of it which is outside the box is hollow, being varnished inside, if of brass, and filled with mercury, in which the bulb of a small delicate thermometer t slides, the stem of which passes through a longitudinal opening on the upper side of the bar as seen in the figure. This thermometer is moved to the exact place, where the moisture begins to condense, and its temperature then indicates the dew-point. For stationary observatories, where ice is easily had, this hygrometer is very convenient, being easily observed.

Fig. 74.

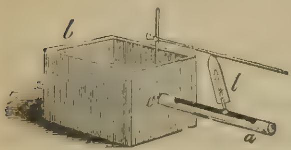


Fig. 75.

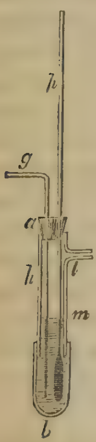
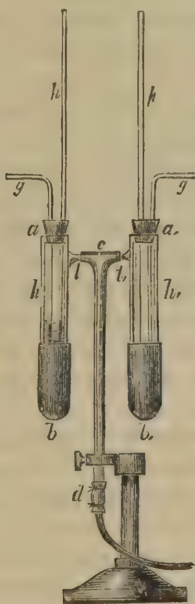


Fig. 76.



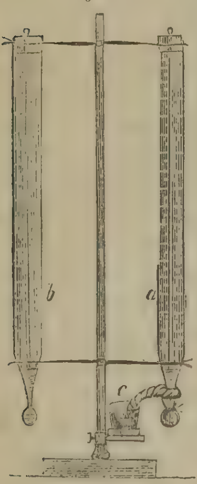
171. Regnault's Hygrometer (*hygromètre condenseur*) is a modification of Daniell's, but so contrived as to be easily managed and to give results of the utmost accuracy. *Fig*. 75 represents it in section. It consists of a glass tube h of 0.8 inch. diameter, having on the side near the top a small horizontal tubulure t. Its lower end is closed by being inserted into an extremely thin and highly polished silver cup or thimble b of the same diameter, and about 1¾ inch. high, but with a round bottom. This and portion of the glass tube up to m is filled with ether, or, as a substitute, with alcohol. The upper end of the instrument is closed by a cork a, through which is

inserted a narrow open glass tube *g*, reaching nearly to the bottom of the silver cup, and a very accurate thermometer *p*, the bulb of which is in the middle of the ether.

The horizontal tube *t* is connected with an aspirator similar to *g*, *fig.* 72, but of smaller size, by which air may be drawn with any desired rapidity through the tube *g*, so as to bubble through the ether. By this contrivance, the evaporation of the ether is under perfect control. When the cooling which it causes reaches the dew-point, the vapors of the atmosphere appear on the outside of the silver cup, and the thermometer is observed. The aspiration is then stopped, and the dew allowed to disappear, and the temperature when this happens, again observed. The true dew-point will then be the mean between these two temperatures. Should it be desired to estimate it with more accuracy, the aspiration is immediately started again, but much slower, and the same experiments repeated. By this contrivance the dew-point may be estimated to $\frac{1}{10}$ of a degree. To be better able to observe the slightest dew by comparison with another similar apparatus, Regnault fixes two such together by the tube *c d*, which connects them both with the aspirator, as shown in *fig.* 76, but the second of which, h_1 is not used at the same time, and therefore contains no ether, and has the tube *g* closed up. The thermometer of this may be used for indicating the temperature of the atmosphere.

172. *August's Psychrometer* (from ψυχρος (psuchros), cold, and μετρον (metron), measure), also called the *Thermo-Hygrometer*, but better known under the name of the *Wet-Bulb Hygrometer*, gives the dew-point or the tension of the vapor in the atmosphere *indirectly*, from the greater rapidity with which water evaporates, the further the quantity of vapor in the atmosphere is from the quantity which would constitute saturation. It consists of two perfectly similar thermometers, see *b* and *a* *fig.* 77, the bulbs of which should be perfectly free in the air. As they are only to indicate the temperatures of the atmosphere, the degrees may be made large and subdivided into fractions. The bulb of the one *a* is covered with muslin. The instrument having been placed in the atmosphere, where exposed to a free change of air, but not to a decided wind, the covered bulb is thoroughly moistened by dipping it to above the bulb in pure water, which should previously have acquired the temperature of the air. The water will then evaporate from the moist-

Fig. 77.



ened bulb and thereby lower its temperature (see Latent Heat under Thermics), so that the quicker the evaporation, the lower its temperature will fall. As soon as the full effect is produced, which generally occurs in from 5 to 10 minutes after its moistening, and is known by the temperature becoming stationary, the thermometer is read off; the other thermometer is also read off at the same time, and gives the temperature of the air. Sometimes, instead of dipping the thermometer into water before observing it, it is kept constantly moistened by a wick dipping into a small vessel *c* with water.

This instrument is also employed, when the temperature of the atmosphere is freezing, and it then acts by the cold produced by the evaporation of the layer of ice, which is formed round the bulb. In this case the thermometer should not be read off before the layer of ice which forms after the moistening of the bulb has become perfectly dry, which will require from 15 to 30 minutes. It is then best to keep the bulb covered permanently with a layer of ice, which should be neither too thin nor too thick, since in both of these cases the temperature of the bulb will not fall to the proper point. It requires much care and practice to regulate the thickness of the ice.

173. To obtain the tension of the vapor in the atmosphere in English inches, from the indications of this instrument, we have the following formula calling this tension f:

$$f = F_1 - \frac{0.480\,(T - T_1)}{1130 - T_1}\,B,$$

in which $T =$ the temperature of the atmosphere in Fah. degrees given by the dry thermometer; $T_1 =$ the temperature in Fah. degrees of the wet-bulb thermometer; $F_1 =$ the maximum tension in English inches for the temperature T_1 of the wet-bulb thermometer, and which is found in Table IX; and $B =$ the stand of the Barometer in English inches.

If the observations are taken below 32°, when the wet-bulb therefore is covered with ice, we must substitute in the above formula, instead of $1130 - T_1$ which represents the latent heat of the vapor, $1272.2 - T_1$ the formula then becoming:

$$f = F_1 - \frac{0.480\,(T - T_1)}{1272.2 - T_1}\,B.$$

Having thus obtained the tension of the vapor in the atmosphere, the relative humidity is easily calculated (164) by dividing this tension by the maximum tension for the temperature T of the atmosphere, given by the dry thermometer, and which tension is found in Table IX. If the dew-point be required, it is easily obtained by taking from Table IX the temperature which corresponds to the tension f, obtained by the above formula.

174. To illustrate this by an example, suppose that the

Dry Therm. $= 68° = T$ *Wet Bulb Therm.* $= 59° = T_1$

Barom. $= 29.922$ *inch.* $= B$

We then have:

$$T - T_1 = 9°$$

and from Table IX, $F_1 = 0.500$ *inch.*

Therefore, by the first formula:

$$f = 0.500 - \frac{0.480 \times 9}{1130 - 59} \times 29.922 = 0.379 \text{ inch;}$$

which is therefore the tension of the vapor in the Atmosphere; and 51°3 which in Table IX corresponds to this tension, is the Dew-Point. From Table IX we then obtain:

Max. Tension for $68° = 0.685$ *inch.*

Therefore:

$$\textit{Relative Humidity} = \frac{0.379}{0.685} = .0.553;$$

or $= 55.3$, *if referred to saturation as* 100.

To avoid these calculations, Tables have been constructed, which give from the temperature T_1 of the wet-bulb thermometer, and the temperature T of the atmosphere or the difference $T - T_1$ between the dry and wet-bulb thermometers, both the tension of the vapor in the atmosphere, and the relative humidity, which at the temperature T of the atmosphere corresponds to this tension, *supposing* the *Barometer* to *remain at the same average stand.* If it should be required to make a correction for the different stands of the barometer, a table may also be constructed for this purpose.

[The formula given by August, of Berlin, the inventor of this instrument, and which is yet used extensively, is: $x = f' - \frac{0.568\ (t - t')}{640 - t'}\ h$; in which x = the tension of vapor in atmosphere in millimetres; t and t' = temperatures of dry and wet bulb thermometers in centigrade degrees; f' = maximum tension of vapors at temperature t', in millimetres; and h = stand of Barometer also in millimetres. By correction of some of the numerical data, Regnault has since altered this into: $x = f' - \frac{0.429\ (t - t')}{610 - t'}\ h$, which he found to give correct results, whenever the relative humidity is less than 0.40 (which results differ not much from those obtained by August's formula, using August's Table of Maximum Tensions, but when taken for a wider range are not so near the truth). But whenever the relative humidity is over 0.40, Regnault has found, that in order to obtain perfectly correct results, it is necessary to substitute the coefficient 0.480 for 0.429, the formula then becoming: $x = f' - \frac{0.480\ (t - t')}{610 - t'}\ h$, and for temp. below the freezing point: $x = f' - \frac{0.480\ (t - t')}{689 - t'}\ h$, which are the formulæ given above, only with the proper substitutions for using English inches and Fahr. degrees. With the same substitutions August's formula becomes: $f = F_1 - \frac{0.568\ (T - T_1)}{1184 - T_1}\ B$, and as corrected by Regnault: $f = F_1 - \frac{0.429\ (T - T_1)}{1130 - T_1}$.]

175. For low temperatures this instrument gives less accurate results, on account of the small differences between the temperatures of the dry and wet-bulb thermometers; and when the temperature of the atmosphere is near the freezing point, its results are very unsatisfactory, on account of the uncertainty in the freezing of the water. Regnault also found that in order to obtain good results, a free change of air is absolutely necessary, so that in a close room its indications are less correct, the wet-bulb thermometer not descending to its proper point, and therefore giving the relative humidity too high. For observations, it is therefore generally placed in an open window, or fixed permanently outside of it. But even when thus placed, the air, if very still, should be agitated about the bulb by fanning. On the other hand, too strong currents of air will affect the results in the opposite direction, so that if the existing wind have a greater velocity than from 15 to 18 feet per second, the instrument should be screened from it. Otherwise, Regnault found that within the ordinary limits given to this instrument, it is not influenced perceptibly by the size or shape of the thermometer-bulb, nor by the thickness of the covering muslin, nor by the manner of moistening it either by immersion of the bulb, or by supplying it by a wick from a small vessel; nor in the latter case, by the length of the wick, or the quantity of water by which it is moistened, provided this be sufficient for complete moistening and full evaporation, so that if supplied from the wick in larger quantity than this, it may even without injury cause a drop to fall occasionally from the bulb, but in no case should it exceed this quantity. The water used for moistening, should be pure, as otherwise by its evaporation it causes too great a deposit of earthy ingredients on the bulb. Rain-water is, therefore, preferable. To remove impurities which collect on the bulb, it should be cleaned, and the covering renewed at least every two or three months.

176. The Psychrometer, from its simplicity and the facility with which it is observed and transported, is almost universally employed for meteorological observations, both by travellers and at stationary observatories. The above-given precautions and some practice in its use, are, however, necessary in order to obtain reliable results.

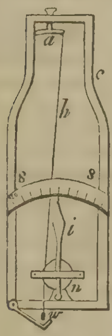
Hygrometers acting by absorption of the vapor.

177. Many organic substances have the property of attracting, by the force of adhesion, vapor from the atmosphere, and of condensing it on their surface and in their pores (see 54), by which they increase their volume or swell. The quantity of vapor which they thus attract or

absorb, varies with the greater or less proportion, which the quantity of vapor in the atmosphere forms of the quantity that would constitute saturation, or in other words, with the relative humidity (164), so that the latter to a certain extent may be measured by the increase or decrease of their volume. Of Hygrometers, acting on this principle, only one deserves a special mention, as giving results which approach to scientific accuracy, viz.

178. *Saussure's Hair Hygrometer.* It consists of a human hair deprived of its natural grease by boiling in a feeble solution of carbonate of soda in water. This hair is suspended in a metallic frame *c fig.* 78, the one end of the hair being attached to a bracket *a*, which may be adjusted by a screw; the other end is attached to the circumference of a small wheel or pulley *n*. The circumference of this wheel has also another groove, in which is fastened and slightly wound around it in the opposite direction, a thin silk thread, to which is attached a small weight *w*, which therefore constantly keeps the hair tense. It will easily be seen, that when the hair by increased moisture of the atmosphere absorbs more vapor and thereby swells, this will be perceptible by its elongation, by which it allows the weight to turn the wheel. When, on the contrary, the humidity of the air diminishes, the hair loses some of the condensed vapor, it contracts and turns the wheel in the opposite direction. The axis of the wheel carries a light index *i*, which is thus made to traverse a graduated scale *s*.

Fig. 78.



179. To construct the scale of this instrument, it is first placed in a close receiver, the bottom of which is covered with water and the sides moistened, by which the air becomes saturated with vapor. The length of the hair having been so adjusted, that the index will then be near the one end of the scale, the point where it then stands, as soon as it becomes stationary, is marked 100°, and corresponds to saturation or a relative humidity of 100. It is then placed, after the removal of the water, in the same close receiver over oil of vitriol, which deprives the air of all the vapor; and the point on the scale where the index then stands, after it has become almost stationary, is marked 0°, which point corresponds to a relative humidity of 0. The distance between 0° and 100° is divided into 100 equal parts, each of which is called 1 degree. These degrees do, however, not correspond to the same numbers of relative humidity. The following table has been given as indicating the different relative humidities corresponding to the different degrees of this hygrometer:

Table of Relative Humidities corresponding to the degrees of Saussure's Hygrometer.

Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.	Saussure's Hygrometer.	Relative Humidity.
0°	0	10°	5	20°	12	30°	19	40°	27	50°	35	60°	44	70°	56	80°	69	90°	83
1°	0	11°	6	21°	12	31°	20	41°	27	51°	36	61°	45	71°	57	81°	70	91°	85
2°	1	12°	6	22°	13	32°	21	42°	28	52°	37	62°	46	72°	58	82°	72	92°	87
3°	1	13°	7	23°	14	33°	22	43°	28	53°	37	63°	47	73°	59	83°	73	93°	88
4°	2	14°	8	24°	15	34°	23	44°	29	54°	38	64°	49	74°	61	84°	75	94°	90
5°	3	15°	8	25°	16	35°	24	45°	30	55°	39	65°	50	75°	62	85°	77	95°	91
6°	3	16°	9	26°	17	36°	24	46°	31	56°	40	66°	51	76°	63	86°	78	96°	93
7°	4	17°	10	27°	18	37°	25	47°	32	57°	41	67°	52	77°	65	87°	79	97°	95
8°	4	18°	11	28°	18	38°	26	48°	33	58°	42	68°	53	78°	66	88°	81	98°	97
9°	5	19°	11	29°	19	39°	26	49°	34	59°	43	69°	55	79°	68	89°	82	99°	98

180. But this instrument is not so uniform, that the above comparison can be relied on.

Saussure's directions (Essais sur l'Hygromètrie, par B. H. de Saussure, Neufchatel, 1783) are: to select fine, soft, not curly, nor splitting hair, *cut* from the head of a living and sane person. A bunch of these of the thickness of a quill is then sewed up between linen, separating them as much as possible. They are then boiled for 30 minutes in a solution of 154 grains of Crystallized Carbonate of Soda in 32 oz. (Troy) of Water, which should be performed in a flask with a long neck, to prevent the evaporation of the water. The bag is then twice boiled for a few minutes in pure water, cut open, and the hairs again washed and separated by moving them to and fro in a large vessel with cold water, after which they are dried in the open air. The hairs should appear clean, soft, polished and transparent, separating easily from each other. If they are rough and adhere, they have either been boiled too long, or the solution has become too strong by the evaporation of the water. The length of the hair in the frame should be about 9½ inch.; the diameter of the pulley on which it acts 0.2 inch. The index should be light, and with the pulley perfectly balanced by itself. The extending weight should not exceed 3 grains; if increased to only 9 grains, the instrument will, after some time, work irregularly. Saussure has also studied the influence of the temperature on it, and gives a table for reducing its indications to the same temperature. He asserts that if his directions are strictly adhered to, the instrument will never vary more than 2 to 3 degrees. By later experiments, Regnault found no greater difference with the same kind of hair, if prepared in one and the same operation; with different kinds of hair, also prepared in the same operation, the difference amounted to nearly 5°; about the same difference (5°) was produced with the same kind of hair, and prepared in the same operation, but with small differences in the weights by which the hairs were extended. *But with different kinds of hair, and prepared in different operations, and having been in use for different lengths of time, the differences amounted in some cases to* 15°, even after the extreme points of the scale had been fixed correctly. Regnault concludes from this, that it is necessary to construct a table for every instrument, by comparing its degrees with known relative humidities of the air, which he produces by placing it in a close receiver with different mixtures of oil of vitriol and water, for which mixtures he has given an elaborate table of tensions; and also to test the instrument from time to time when in use. He also proposes to remove the natural grease by placing the hairs for 24 hours in ether, by which they retain their strength and solidity, and acquire almost the same sensibility. As by placing the instrument in perfectly dry air in order to fix the 0°, it requires several days to become moderately stationary, and the hair continues to con-

tract, though much less, even for several months, he considers the state to which it is thus reduced as unnatural, and therefore permanently injuring its hygrometrical properties. As the air also never reaches this degree, he proposes, therefore, to drop the present 0° altogether, and to begin the scale from a point, which corresponds to a relative humidity of 20°, and which is produced in a close receiver at the temperature of 42°.83 Fah. by the mixture of oil of vitriol and water, which has the chemical composition of 1 atom of sulphuric acid, and 5 atoms of water, being represented by the formula, $SO_3 + 5\ HO$.

181. *Hygroscopes.* Many other instruments have been constructed from other organic substances, acting on the same principle as the hair hygrometer; but all these have no scientific value whatever, as none of them can be relied upon for indicating the relative humidity, even only approximately. They are therefore not hygrometers, but *hygroscopes* (from ὑγρος (hugros), and σκοπεω (skopeo), I observe), and as such they may be used with advantage to indicate a mere increase or decrease in the moisture of the atmosphere. Of such may be mentioned, strips or bars of *whalebone* or *wood*, cut across the grain. The former may be reduced to a thin thread or band, and may be made to act on a wheel with an index in a similar manner as the hair. All *twisted* strings made of *vegetable fibres*, as hempen cords, or of *animal membranes*, as cat-gut or violin strings, will swell by moisture and thus by the increase in their diameter untwist themselves, or, if prevented from this, become shorter by the increased twist. A piece of violin string, if properly prepared, may thus, by its untwisting, be made to turn back the hood or cowl from the head of a figure in dry weather and to replace it in damp weather; or to raise its arm and unfurl an umbrella; or to turn a lever so as to show alternately through a window or before the door of a toy-house, two different figures, representing rainy and fine weather. The *beard* of the husk around the seed of Sensitive Oats (Avena sensitiva), is naturally twisted or coiled as a double spiral, so that if one end be fastened in the centre of a graduated circle, and a light index of straw attached by sealing-wax to the other, the latter will traverse the circular scale by the coiling or uncoiling of the beard by the moisture in the air. The *bladder* of a rat or squirrel, may also be converted into a hygroscope, by tying its mouth over the end of an open glass-tube and filling the bladder and part of the tube with mercury. By the contraction or swelling of the bladder by the change in moisture, the mercury will rise or fall in the tube. *Whalebone*, reduced to the thinness of fine paper, *goldbeater's skin*, and thin sheets of *gelatine* or *glue*, will show such sensitiveness to moisture, that if cut into figures, as fishes, etc., and placed in the palm of the hand, the natural moisture of the latter will cause the side next to it to swell, and the figure to curl itself up.

TABLE I. *Correction for reducing the Height of the Mercurial column of the Barometer to Standard temperature of 32°. Giving the correction for the expansion of the mercury* only. *Applicable to Barometers* mounted in wood, *with scale engraved on ivory or short brass plate.*

Temp. Fah.	Height of Mercurial Column in English Inches.							Temp. Fah.	Height of Mercurial Column in English Inches.						
	28	28.5	29	29.5	30	30.5	31		28	28.5	29	29.5	30	30.5	31
22°	+.028	+.029	+.029	+.030	+.030	+.031	+.031	61°	—.081	—.083	—.084	—.085	—.087	—.088	—.090
24°	023	.023	.023	.024	.024	.025	.025	62°	.084	.085	.087	.088	.090	.091	.093
26°	017	.017	.017	.018	.018	.018	.019	63°	.087	.088	.090	.091	.093	.094	.096
28°	.011	.011	.012	.012	.012	.012	.012	64°	.089	.091	.093	.094	.096	.097	.099
30°	.006	.006	.006	.006	.006	.006	.006	65°	.092	.094	.096	.097	.099	.100	.102
31°	+.003	+.003	+.003	+.003	+.003	+.003	+.003	66°	—.095	—.097	—.098	—.100	—.102	—.103	—.105
32°	0	0	0	0	0	0	0	67°	.098	.100	.101	.103	.105	.107	.108
33°	—.003	.003	—.003	—.003	—.003	—.003	—.003	68°	.101	.102	.104	.106	.108	.110	.111
34°	.006	.006	.006	.006	.006	.006	.006	69°	.103	.105	.107	.109	.111	.113	.114
35°	.008	.009	.009	.009	.009	.009	.009	70°	.106	.108	.110	.112	.114	.116	.118
36°	—.011	—.011	—.012	—.012	—.012	—.012	—.012	71°	—.109	—.111	—.113	—.115	—.117	—.119	—.121
37°	.014	.014	.015	.015	.015	.015	.016	72°	.112	.114	.116	.118	.120	.122	.124
38°	.017	.017	.017	.018	.018	.018	.019	73°	.114	.117	.119	.121	.123	.125	.127
39°	.020	.020	.020	.021	.021	.021	.022	74°	.117	.119	.121	.124	.126	.128	.130
40°	.022	.023	.023	.024	.024	.024	.025	75°	.120	.122	.124	.126	.129	.131	.133
41°	—.025	—.026	—.026	—.027	—.027	—.027	—.028	76°	—.123	—.125	—.127	—.129	—.132	—.134	—.136
42°	.028	.029	.029	.030	.030	.031	.031	77°	.126	.128	.130	.132	.135	.137	.139
43°	.031	.031	.032	.032	.033	.034	.034	78°	.128	.131	.133	.135	.138	.140	.142
44°	.034	.034	.035	.035	.036	.037	.037	79°	.131	.133	.136	.138	.141	.143	.145
45°	.036	.037	.038	.038	.039	.040	.040	80°	.134	.136	.139	.141	.143	.146	.148
46°	—.039	—.040	—.041	—.041	—.042	—.043	—.043	81°	—.137	—.139	—.142	—.144	—.146	—.149	—.151
47°	.042	.043	.044	.044	.045	.046	.047	82°	.139	.142	.144	.147	.149	.152	.154
48°	.045	.046	.046	.047	.048	.049	.050	83°	.142	.145	.147	.150	.152	.155	.158
49°	.048	.048	.049	.050	.051	.052	.053	84°	.145	.148	.150	.153	.155	.158	.161
50°	.050	.051	.052	.053	.054	.055	.056	85°	.148	.150	.153	.156	.158	.161	.164
51°	—.053	—.054	—.055	—.056	—.057	—.058	—.059	86°	—.151	—.153	—.156	—.159	—.161	—.164	—.167
52°	.056	.057	.058	.059	.060	.061	.062	87°	.153	.156	.159	.162	.164	.167	.170
53°	.059	.060	.061	.062	.063	.064	.065	88°	.156	.159	.162	.164	.167	.170	.173
54°	.062	.063	.064	.065	.066	.067	.068	89°	.159	.162	.164	.167	.170	.173	.176
55°	.064	.066	.067	.068	.069	.070	.071	90°	.162	.165	.167	.170	.173	.176	.179
56°	—.067	—.068	—.070	—.071	—.072	—.073	—.074	92°	—.167	—.170	—.173	—.176	—.179	—.182	—.185
57°	.070	.071	.072	.074	.075	.076	.077	94°	.173	.176	.179	.182	.185	.188	.191
58°	.073	.074	.075	.077	.078	.079	.081	96°	.178	.181	.185	.188	.191	.194	.197
59°	.076	.077	.078	.080	.081	.082	.084	98°	.184	.187	.190	.194	.197	.200	.203
60°	.078	.080	.081	.083	.084	.085	.087	100°	.189	.193	.196	.199	.203	.206	.210

TABLE II. *Correction for reducing* Observed *Height of Barom. to Stand. Temp. of 32° Fah.* The Scale being of brass and extending the whole length of instrument. Formula in note to par. 77, p. 49.

Observed Temp. of Barom. Fah.	Observed Height in English Inches.									
	26.5	**27**	**27.5**	**28**	**28.5**	**29**	**29.5**	**30**	**30.5**	**31**
0°	+.068	+.069	+.071	+.072	+.073	+.074	+.076	+.077	+.078	+.080
1	.065	.067	.068	.069	.071	.072	.073	.074	.076	.077
2	.063	.064	.066	.067	.068	.069	.070	.072	.073	.074
3	.061	.062	.063	.064	.065	.067	.068	.069	.070	.071
4	.058	.059	.061	.062	.063	.064	.065	.066	.067	.068
5	.056	.057	.058	.059	.060	.061	.062	.063	.065	.066
6	+.054	+.055	+.056	+.057	+.058	+.059	+.060	+.061	+.062	+.063
7	.051	.052	.053	.054	.055	.056	.057	.058	.059	.060
8	.049	.050	.051	.052	.053	.054	.054	.055	.056	.057
9	.046	.047	.048	.049	.050	.051	·052	.053	.054	.054
10	.044	.045	.046	.047	.047	.048	.049	.050	.051	.052
11	+.042	+.042	+.043	+.044	+.045	+.046	+.046	+.047	+.048	+.049
12	.039	.040	.041	.042	.042	.043	.044	.045	.045	.046
13	.037	.038	.038	.039	.040	.040	.041	.042	.043	.043
14	.035	.035	.036	.037	.037	.038	.038	.039	.040	.040
15	.032	.033	.033	.034	.035	.035	.036	.036	.037	.038
16	+.030	+.030	+.031	+.032	+.032	+.033	+.033	+.034	+.034	+.035
17	.027	.028	.028	.029	.030	.030	.031	.031	.032	.032
18	.025	.025	.026	.026	.027	.027	.028	.028	.029	.029
19	.023	.023	.024	.024	.024	.025	.025	.026	.026	.027
20	.020	.021	.021	.021	.022	.022	.023	.023	.023	.024
21	+.018	+.018	+.019	+.019	+.019	+.020	+.020	+.020	+.021	+.021
22	.016	.016	.016	.016	.017	.017	.017	.018	.018	.018
23	.013	.013	.014	.014	.014	.014	.015	.015	.015	.015
24	.011	.011	.011	.011	.012	.012	.012	.012	.012	.013
25	.008	.009	.009	.009	.009	.009	.009	.009	.010	.010
26	+.006	+.006	+.006	+.006	+.006	+.007	+.007	+.007	+.007	+.007
27	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
28	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
29	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001	—.001
30	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
31	—.006	—.006	—.006	—.006	—.006	—.007	—.007	—.007	—.007	—.007
32	.008	.008	.009	.009	.009	.009	.009	·009	.010	.010
33	.011	.011	.011	.011	.012	.012	.012	.012	.012	.012
34	.013	.013	.014	.014	.014	.014	.015	.015	.015	.015
35	.015	.016	.016	.016	.017	.017	.017	.018	.018	.018
36	—.018	—.018	—.019	—.019	—.019	—.020	—.020	—.020	—·021	—.021
37	.020	.021	.021	.021	.022	.022	.022	.023	.023	.024
38	.023	.023	.023	.024	.024	.025	.025	.026	.026	.026
39	.025	.025	.026	.026	.027	.027	.028	.028	.029	.029
40	.027	.028	.028	.029	.029	.030	.030	.031	.031	.032
41	—.030	—.030	—.031	—.031	—.032	—.033	—.033	—.034	—.034	—.035
42	.032	.033	.033	.034	.034	.035	.036	.036	.037	.037
43	.034	.035	.036	.036	.037	.038	.038	.039	.040	.040
44	.037	.037	.038	.039	.040	.040	.041	.042	.042	.043
45	.039	.040	.041	.041	.042	.043	.044	.044	.045	.046
46	—.042	—.042	—.043	—.044	—.045	—.045	—.046	—.047	—.048	—.049
47	.044	.045	.046	.046	.047	.048	.049	.050	.051	.051
48	.046	.047	.048	.049	.050	.051	.052	.052	.053	.054
49	.049	.050	.050	.051	.052	.053	.054	.055	.056	.057
50	.051	.052	.053	.054	.055	.056	.057	.058	.059	.060

TABLE II. *Correction for reducing* Observed *Height of Barom. to Stand. Temp. of* 32° *Fah.*

The Scale being of brass and extending the whole length of instrument. Formula in note to par. 77, p. 49.

Observed Temp. of Barom. Fah.	Observed Height in English Inches.									
	26.5	**27**	**27.5**	**28**	**28.5**	**29**	**29.5**	**30**	**30.5**	**31**
51°	—.053	—.054	—.055	—.056	—.057	—.058	—.059	—.060	—.061	—.062
52	.056	.057	.058	.059	.060	.061	.062	.063	.064	.065
53	.058	.059	.060	.061	.063	.064	.065	.066	.067	.068
54	.060	.062	.063	.064	.065	.066	.067	.068	.070	.071
55	.063	.064	.065	.066	.068	.069	.070	.071	.072	.073
56	—.065	—.066	—.068	—.069	—.070	—.071	—.073	—.074	—.075	—.076
57	.068	.069	.070	.071	.073	.074	.075	.076	.078	.079
58	.070	.071	.073	.074	.075	.077	.078	.079	.081	.082
59	.072	.074	.075	.076	.078	.079	.080	.082	.083	.085
60	.075	.076	.077	.079	.080	.082	.083	.085	.086	.087
61	—.077	—.078	—.080	—.081	—.083	—.084	—.086	—.087	—.089	—.090
62	.079	.081	.082	.084	.085	.087	.088	.090	.091	.093
63	.082	.083	.085	.086	.088	.089	.091	.093	.094	.096
64	.084	.086	.087	.089	.090	.092	.094	.095	.097	.098
65	.086	.088	.090	.091	.093	.095	.096	.098	.100	.101
66	—.089	—.090	—.092	—.094	—.096	—.097	—.099	—.101	—.102	—.104
67	.091	.093	.095	.096	.098	.100	.102	.103	.105	.107
68	.094	.095	.097	.099	.101	.102	.104	.106	.108	.109
69	.096	.098	.100	.101	.103	.105	.107	.109	.110	.112
70	.098	.100	.102	.104	.106	.108	.109	.111	.113	.115
71	—.101	—.102	—.104	—.106	—.108	—.110	—.112	—.114	—.116	—.118
72	.103	.105	.107	.109	.111	.113	.115	.117	.119	.120
73	.105	.107	.109	.111	.113	.115	.117	.119	.121	.123
74	.108	.110	.112	.114	.116	.118	.120	.122	.124	.126
75	.110	.112	.114	.116	.118	.120	.122	.125	.127	.129
76	—.112	—.114	—.117	—.119	—.121	—.123	—.125	—.127	—.129	—.131
77	.115	.117	.119	.121	.123	.126	.128	.130	.132	.134
78	.117	.119	.122	.124	.126	.128	.130	.133	.135	.137
79	.118	.122	.124	.126	.128	.131	.133	.135	.137	.140
80	.122	.124	.126	.129	.131	.133	.136	.138	.140	.143
81	—.124	—.126	—.129	—.131	—.134	—.136	—.138	—.141	—.143	—.145
82	.126	.129	.131	.134	.136	.138	.141	.143	.146	.148
83	.129	.131	.134	.136	.139	.141	.143	.146	.148	.151
84	.131	.134	.136	.139	.141	.144	.146	.149	.151	.154
85	.133	.136	.139	.141	.144	.146	.149	.151	.154	.156
86	—.136	—.138	—.141	—.144	—.146	—.149	—.151	—.154	—.156	—.159
87	.138	.141	.143	.146	.149	.151	.154	.157	.159	.162
88	.141	.143	.146	.149	.151	.154	.157	.159	.162	.165
89	.143	.146	.148	.151	.154	.156	.159	.162	.165	.167
90	.145	.148	.151	.153	.156	.159	.162	.164	.167	.170
91	—.148	—.150	—.153	—.156	—.159	—.162	—.165	—.167	—.170	—.173
92	.150	.153	.156	.158	.161	.164	.167	.170	.172	.175
93	.152	.155	.158	.161	.164	.167	.170	.172	.175	.178
94	.155	.157	.161	.163	.166	.169	.172	.175	.177	180
95	.157	.160	.163	.166	.169	.172	.175	.178	.180	.183
96	—.159	—.162	—.165	—.168	—.171	—.174	—.178	—.181	—.183	—.186
97	.162	.165	.168	.171	.174	.177	.180	.183	.186	.189
98	.164	.167	.170	.173	.176	.179	.183	.186	.188	.191
99	.166	.169	.173	.176	.179	.182	.185	.188	.191	.194
100	.169	.172	.175	.178	.181	.184	.188	.191	.194	.197

TABLE III. *Giving the different distances from the* uppermost accessible *limit of the Atmos.* (5.7 *miles*) *corresponding to the different heights of the Barom.*
The temp. of the Atmosphere being 32°. See Pn. par. 95, page 67.*

Barom. Inches.	Distances in Feet.	Diff. with proportional parts for thousandths of Inches	Barom. Inches.	Distances in Feet.	Diff. with proportional parts for thousandths of Inches	Barom. Inches.	Distances in Feet.	Diff. with proportional parts for thousandths of Inches.
28.00	27425·3		28.50	27887·7		29.00	28342·1	
.01	27434·6		.51	27896·9		.01	28351·1	
.02	27444·0		.52	27906·0		.02	28360·1	
.03	27453·3		.53	27915·2		.03	28369·1	
.04	27462·6		.54	27924·3		.04	28378·1	
.05	27471·9	9.4	.55	27933·5	9.1	.05	28387·1	9.0
.06	27481·3		.56	27942·6		.06	28396·1	
.07	27490·6	1 0.9	.57	27951·8	1 0.9	.07	28405·0	1 0.9
.08	27499·9	2 1.9	.58	27960·9	2 1.8	.08	28414·0	2 1.8
.09	27509·2	3 2.8	.59	27970·1	3 2.7	.09	28423·0	3 2.7
		4 3.8			4 3.6			4 3.6
28.10	27518·4	5 4.7	28.60	27979·2	5 4.6	29.10	28432·0	5 4.5
.11	27527·7	6 5.6	.61	27988·3	6 5.5	.11	28441·0	6 5.4
.12	27537·0	7 6.6	.62	27997·5	7 6.4	.12	28450·0	7 6.3
.13	27546·3	8 7.5	.63	28006·6	8 7.3	.13	28458·9	8 7.2
.14	27555·6	9 8.5	.64	28015·7	9 8.2	.14	28467·9	9 8.1
.15	27564·9		.65	28024·8		.15	28476·9	
.16	27574·2		.66	28034·0		.16	28485·8	
.17	27583·5		.67	28043·1		.17	28494·8	
.18	27592·7		.68	28052·2		.18	28503·8	
.19	27602·0		.69	28061·3		.19	28512·7	
		9.3						
28.20	27611·3	1 0.9	28.70	28070·5		29.20	28521·7	
.21	27620·6	2 1.9	.71	28079·6		.21	28530·6	
.22	27629·8	3 2.8	.72	28088·7		.22	28539·6	
.23	27639·1	4 3.7	.73	28097·8		.23	28548·5	
.24	27648·3	5 4.7	.74	28106·9		.24	28557·5	
.25	27657·6	6 5.6	.75	28115·9		.25	28566·4	
.26	27666·8	7 6.5	.76	28125·0		.26	28575·4	
.27	27676·1	8 7.4	.77	28134·1		.27	28584·3	
.28	27685·3	9 8.4	.78	28143·2		.28	28593·2	
.29	27694·6		.79	28152·2		.29	28602·2	
28.30	27703·7		28.80	28161·3		29.30	28611·1	
.31	27712·9		.81	28170·4		.31	28620·0	
.32	27722·2		.82	28179·4		.32	28628·9	
.33	27731·4		.83	28188·5	9.0	.33	28637·8	8.9
.34	27740·6	9.2	.84	28197·5		.34	28646·7	
.35	27749·8		.85	28206·6	1 0.9	.35	28655·6	1 0.9
.36	27759·1	1 0.9	.86	28215·6	2 1.8	.36	28664·5	2 1.8
.37	27768·3	2 1.8	.87	28224·7	3 2.7	.37	28673·4	3 2.7
.38	27777·5	3 2.8	.88	28233·7	4 3.6	.38	28682·3	4 3.6
.39	27786·7	4 3.7	.89	28242·8	5 4.5	.39	28691·2	5 4.5
		5 4.6			6 5.4			6 5.5
28.40	27795·8	6 5.5	28.90	28251·8	7 6.3	29.40	28700·0	7 6.2
.41	27805·0	7 6.4	.91	28260·8	8 7.2	.41	28708·9	8 7.1
.42	27814·2	8 7.4	.92	28269·9	9 8.1	.42	28717·8	9 8.0
.43	27823·4	9 8.3	.93	28278·9		.43	28726·6	
.44	27832·6		.94	28287·9		.44	28735·5	
.45	27841·8		.95	28296·9		.45	28744·4	
.46	27851·0		.96	28306·0		.46	28753·3	
.47	27860·2		.97	28315·0		.47	28762·1	
.48	27869·3		.98	28324·0		.48	28771·0	
.49	27878·5		.99	28333·0		.49	28779·9	

* The distances in this Table have been obtained by deducting 59632.6 feet from those given by the formula, which refer to the upper *sensible* limit (about 17 miles above the earth).

TABLE III (Continued). *Giving the different distances from the* uppermost accessible *limit of the Atmos. (5.7 miles) corresponding to the different heights of the Barom.*

The temp. of the Atmosphere being 32°. See Pn. par. 95, page 67.*

Barom. Inches.	Distances in Feet.	Diff. with proportional parts for thousandths of Inch.	Barom. Inches.	Distances in Feet.	Diff. with proportional parts for thousandths of Inch.	Barom. Inches.	Distances in Feet.	Diff. with proportional parts for thousandths of Inch.
29.50	28788·7		30.00	29227·8		30.50	29659·6	
.51	28797·5		.01	29236·5		.51	29668·1	
.52	28806·4		.02	29245·2		.52	29676·7	
.53	28815·2		.03	29253·9		.53	29685·2	
.54	28824·1		.04	29262·6		.54	29693·8	
.55	28832·9		.05	29271·3		.55	29702·3	
.56	28841·8	8.9	.06	29280·0	8.7	.56	29710·9	8.6
.57	28850·6	1 0.9	.07	29288·7	1 0.9	.57	29719·4	1 0.9
.58	28859·4	2 1.8	.08	29297·3	2 1.7	.58	29727·9	2 1.7
.59	28868·3	3 2.7	.09	29306·0	3 2.6	.59	29736·5	3 2.6
		4 3.6			4 3.5			4 3.4
29.60	28877·1	5 4.5	30.10	29314·7	5 4.4	30.60	29745·0	5 4.3
.61	28885·9	6 5.3	.11	29323·4	6 5.2	.61	29753·5	6 5.2
.62	28894·7	7 6.2	.12	29332·0	7 6.1	.62	29762·1	7 6.0
.63	28903·6	8 7.1	.13	29340·7	8 7.0	.63	29770·6	8 6.9
.64	28912·4	9 8.0	.14	29349·3	9 7.8	.64	29779·1	9 7.7
.65	28921·2		.15	29358·0		.65	29787·6	
.66	28930·0		.16	29366·7		.66	29796·2	
.67	28938·8		.17	29375·3		.67	29804·7	
.68	28947·6		.18	29384·0		.68	29813·2	
.69	28956·4		.19	29392·6		.69	29821·7	
		8.8						8.5
29.70	28965·2		30.20	29401·3		30.70	29830·2	
.71	28974·0	1 0.9	.21	29409·9		.71	29838·7	1 0·9
.72	28982·8	2 1.8	.22	29418·6		.72	29847·2	2 1.7
.73	28991·6	3 2.6	.23	29427·2		.73	29855·7	3 2.6
.74	29000·4	4 3.5	.24	29435·9		.74	29864·2	4 3.4
.75	29009·1	5 4.4	.25	29444·5		.75	29872·7	5 4.3
.76	29017·9	6 5.3	.26	29453·2		.76	29881·2	6 5.1
.77	29026·7	7 6.2	.27	29461·8		.77	29889·7	7 6.0
.78	29035·5	8 7.0	.28	29470·4		.78	29898·2	8 6.8
.79	29044·2	9 7.9	.29	29479·1		.79	29906·7	9 7.7
29.80	29053·1		30.30	29487·7		30.80	29915·2	
.81	29061·9		.31	29496·3		.81	29923·7	
.82	29070·6		.32	29504·9		.82	29932·2	
.83	29079·4		.33	29513·6		.83	29940·7	
.84	29088·1		.34	29522·2		.84	29949·2	
.85	29096·9		.35	29530·8		.85	29957·6	
.86	29105·6	8.7	.36	29539·4	8.6	.86	29966·1	
.87	29114·4	1 0.9	.37	29548·0	1 0.9	.87	29974·6	8.4
.88	29123·1	2 1.7	.38	29556·6	2 1.7	.88	29983·5	1 0.8
.89	29131·9	3 2.6	.39	29565·2	3 2.6	.89	29991·1	2 1.7
		4 3.5			4 3.4			3 2.5
29.90	29140·6	5 4.4	30.40	29573·8	5 4.3	30.90	30000·0	4 3.4
.91	29149·3	6 5.2	.41	29582·4	6 5.2	.91	30008·5	5 4.2
.92	29158·1	7 6.1	.42	29591·0	7 6.0	.92	30016·9	6 5.0
.93	29166·8	8 7.0	.43	29599·6	8 6.9	.93	30025·4	7 5.9
.94	29175·5	9 7.8	.44	29608·2	9 7.7	.94	30033·8	8 6.7
.95	29184·2		.45	29616·7		.95	30042·3	9 7.6
.96	29193·0		.46	29625·3		.96	30050·7	
.97	29201·7		.47	29633·9		.97	30059·2	
.98	29210·4		.48	29642·5		.98	30067·6	
.99	29219·1		49	29651·0		.99	30076·1	

* To avoid too large numbers, the distances in this Table have not been referred to the upper *sensible* limit (17 miles), but to the uppermost *accessible* limit (5.7 miles), by deducting 59633.6 feet from those obtained by the indicated method.

TABLE IV. *Correction for* Latitude, *on account of Decrease of Gravity from Pole to Equator.*

To be applied to *Height* obtained from Barometric Observations, see par. 95, page 68.

ADD this correction if *Lat. less* than 45°; DEDUCT if *Lat. greater* than 45°.

Latitude.		Obtained Height.								
		1 Foot.	2 Feet.	3 Feet.	4 Feet.	5 Feet.	6 Feet.	7 Feet.	8 Feet.	9 Feet
Add for.	Deduct for.	Thousandths of Feet.	Thousandths of Feet.	Thousandths of Feet.	Thousandths of Feet.	Thousandths of Feet.	Thousandths of Feet.	Thousandths of Feet.	Thousandths of Feet.	Thousandths of Feet.
0°	90°	2.837	5.674	8.511	11.348	14.186	17.023	19.860	22.697	25.534
1°	89°	2.835	5.671	8.506	11.342	14.177	17.012	19.848	22.683	25.518
2°	88°	2.830	5.660	8.491	11.321	14.151	16.981	19.811	22.642	25.472
3°	87°	2.822	5.643	8.465	11.286	14.108	16.929	19.751	22.573	25.394
4°	86°	2.810	5.619	8.429	11.238	14.047	16.857	19.666	22.476	25.285
5°	85°	2.794	5.588	8.382	11.176	13.970	16.764	19.558	22.352	25.146
6°	84°	2.775	5.550	8.325	11.100	13.876	16.651	19.426	22.201	24.976
7°	83°	2.753	5.506	8.259	11.011	13.764	16.517	19.270	22.023	24.775
8°	82°	2.727	5.454	8.182	10.909	13.636	16.363	19.090	21.818	24.545
9°	81°	2.698	5.397	8.095	10.793	13.491	16.190	18.888	21.586	24.284
10°	80°	2.666	5.332	7.998	10.664	13.330	15.996	18.662	21.328	23.994
11°	79°	2.631	5.261	7.892	10.522	13.153	15.783	18.413	21.044	23.675
12°	78°	2.592	5.184	7.776	10.367	12.959	15.551	18.142	20.735	23.326
13°	77°	2.550	5.100	7.650	10.200	12.750	15.300	17.850	20.400	22.950
14°	76°	2.505	5.010	7.515	10.020	12.525	15.033	17.535	20.040	22.545
15°	75°	2.457	4.914	7.371	9.828	12.285	14.742	17.199	19.656	22.113
16°	74°	2.406	4.812	7.218	9.624	12.030	14.436	16.842	19.248	21.654
17°	73°	2.352	4.704	7.056	9.408	11.760	14.112	16.464	18.817	21.169
18°	72°	2.295	4.591	6.886	9.181	11.476	13.772	16.067	18.362	20.657
19°	71°	2.236	4.471	6.707	8.943	11.178	13.414	15.650	17.885	20.121
20°	70°	2.173	4.347	6.520	8.693	10.867	13.040	15.213	17.387	19.560
21°	69°	2.108	4.217	6.325	8.434	10.542	12.650	14.759	16.867	18.975
22°	68°	2.041	4.082	6.123	8.163	10.204	12.245	14.286	16.327	18.368
23°	67°	1.971	3.942	5.912	7.883	9.854	11.825	13.796	15.767	17.737
24°	66°	1.898	3.797	5.695	7.594	9.492	11.390	13.289	15.187	17.086
25°	65°	1.824	3.647	5.471	7.295	9.118	10.942	12.766	14.589	16.413
26°	64°	1.747	3.493	5.240	6.987	8.734	10.480	12.227	13.974	15.720
27°	63°	1.668	3.335	5.003	6.670	8.338	10.006	11.673	13.341	15.008
28°	62°	1.587	3.173	4.756	6.346	7.932	9.519	11.105	12.692	14.278
29°	61°	1.503	3.007	4.510	6.014	7.517	9.021	10.524	12.028	13.531
30°	60°	1.419	2.837	4.256	5.674	7.093	8.511	9.930	11.348	12.767
31°	59°	1.332	2.664	3.996	5.328	6.660	7.992	9.324	10.656	11.987
32°	58°	1.244	2.487	3.731	4.975	6.218	7.462	8.706	9.950	11.193
33°	57°	1.154	2.308	3.462	4.616	5.770	6.924	8.078	9.232	10.386
34°	56°	1.063	2.126	3.188	4.251	5.314	6.377	7.440	8.502	9.565
35°	55°	0.970	1.941	2.911	3.881	4.852	5.822	6.792	7.763	8.733
36°	54°	0.877	1.753	2.630	3.507	4.384	5.260	6.137	7.014	7.890
37°	53°	0.782	1.564	2.346	3.128	3.910	4.692	5.474	6.256	7.038
38°	52°	0.686	1.373	2.059	2.745	3.432	4.118	4.805	5.491	6.177
39°	51°	0.590	1.180	1.767	2.360	2.949	3.539	4.129	4.719	5.309
40°	50°	0.493	0.985	1.478	1.971	2.463	2.956	3.449	3.941	4.434
41°	49°	0.395	0.790	1.184	1.579	1.974	2.369	2.764	3.159	3.554
42°	48°	0.297	0.593	0.890	1.186	1.483	1.779	2.076	2.372	2.669
43°	47°	0.198	0.396	0.594	0.792	0.990	1.187	1.385	1.583	1.781
44°	46°	0.099	0.198	0.297	0.396	0.495	0.594	0.693	0.792	0.891
45°	45°	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

TABLE V. *Correction for Altitude, on account of Decrease of Gravity from level of sea upward into the Atmos. To be applied to Height obtained from Barom. Observ., see par. 95, p. 68.*

Obtained Height in Feet.	Correc. to be added. Feet.	Obtained Height in Feet.	Correc. to be added. Feet.	Obtain'd Height in Feet.	Correc. to be added. Feet.	Obtain'd Height in Feet.	Correc. to be added. Feet.	Obtain'd Height in Feet.	Correc. to be added. Feet.
200	0.502	5200	14.303	10200	30.492	15200	49.087	20200	69.876
400	1.008	5400	14.905	10400	31.196	15400	49.880	20400	70.959
600	1.518	5600	15.511	10600	31.897	15600	50.677	20600	71.851
800	2.032	5800	16.120	10800	32.602	15800	51.478	20800	72.748
1000	2.550	6000	16.734	11000	33.312	16000	52.282	21000	73.649
1200	3.071	6200	17.351	11200	34.024	16200	53.092	21200	74.553
1400	3.596	6400	17.972	11400	34.741	16400	53.904	21400	75.461
1600	4.125	6600	18.597	11600	35.462	16600	54.721	21600	76.374
1800	4.658	6800	19.225	11800	36.186	16800	55.541	21800	77.289
2000	5.195	7000	19.858	12000	36.914	17000	56.365	22000	78.209
2200	5.735	7200	20.494	12200	37.646	17200	57.193	22200	79.133
2400	6.280	7400	21.134	12400	38.382	17400	58.024	22400	80.060
2600	6.828	7600	21.778	12600	39.122	17600	58.860	22600	80.991
2800	7.380	7800	22.426	12800	39.866	17800	59.699	22800	81.926
3000	7.936	8000	23.733	13000	40.613	18000	60.542	23000	82.865
3200	8.496	8200	24.165	13200	41.364	18200	61.389	23200	83.808
3400	9.059	8400	24.392	13400	42.119	18400	62.240	23400	84.755
3600	9.627	8600	25.055	13600	42.878	18600	63.095	23600	85.705
3800	10.198	8800	25.722	13800	43.641	18800	63.953	23800	86.659
4000	10.773	9000	26.393	14000	44.407	19000	64.815	24000	87.617
4200	11.352	9200	27.068	14200	45.177	19200	65.681	24200	88.579
4400	11.934	9400	27.746	14400	45.952	19400	66.565	24400	89.545
4600	12.521	9600	28.428	14600	46.730	19600	67.425	24600	90.514
4800	13.111	9800	29.115	14800	47.512	19800	68.303	24800	91.488
5000	13.705	10000	29.804	15000	48.297	20000	69.184	25000	92.465

TABLE VI. *For the conversion of French into English, and English into French measures.*

French Millimetres.	English Inches.	English Inches.	French Millimetres.
1	0.03937079	1	25.39954
2	0.07874158	2	50.79908
3	0.11811237	3	76.19862
4	0.15748316	4	101.59816
5	0.19685395	5	126.99770
6	0.23622474	6	152.39724
7	0.27559553	7	177.79678
8	0.31496632	8	203.19632
9	0.35433711	9	228.59586
720	28.34697	27	685.78758
730	28.74068	28	711.18712
740	29.13438	29	736.58666
750	29.52809	30	761.98620
760	29.92180	31	787.38574

1 French Gramme Weight = 15.433 Engl. grains.
1 Fr. Kilogramme = 2.2047 Engl. pounds Av.d.p.

French Metres.	English Feet.	English Feet.	French Metres.
1	3.2808992	1	0.30479449
2	6.5617984	2	0.60958898
3	9.8426976	3	0.91438347
4	13.1235968	4	1.21917796
5	16.4044960	5	1.52397245
6	19.6853952	6	1.82876694
7	22.9662944	7	2.13356143
8	26.2471936	8	2.43835592
9	29.5280928	9	2.74315041

1 Paris or old French Foot = 1.065765 English Foot.
1 " " " Inch = 1.065765 " Inch.
1 " " " Line = 0.088814 " "
1 French Litre = 61.0275 English cubic Inches.
1 Engl. Wine Gallon = 231.044 Engl. cubic Inches.
1 Engl. cubic Inch = 0.00432818 Engl. Wine Gal.
1 Eng. cub. In. = 252.458 Eng. grains of Water of 62°.
1000 Eng. gr's Water of 62° = 3.961054 Eng. cub. In.

Table VII. *Giving the Maximum Tension or Elastic Force of Vapor of Water for every 0.2 degree from 214° to 185°. Pn. par. 87 page 58, and par. 139 page 94.*

Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.
214°.0	31.132	0.123	**204°.0**	25.468	0.104	**194°.0**	20.687	0.087
213°.8	31.009	0.122	203°.8	25.364	0.103	193°.8	20.600	0.087
213°.6	30.887	0.122	203°.6	25.261	0.103	193°.6	20.513	0.087
213°.4	30.765	0.122	203°.4	25.158	0.103	193°.4	20.426	0.086
213°.2	30.643	0.121	203°.2	25.055	0.103	193°.2	20.340	0.086
213°.0	30.522	0.121	**203°.0**	24.952	0.102	**193°.0**	20.254	0.086
212°.8	30.401	0.120	202°.8	24.850	0.102	192°.8	20.168	0.086
212°.6	30.281	0.120	202°.6	24.748	0.102	192°.6	20.082	0.085
212°.4	30.161	0.120	202°.4	24.646	0.101	192°.4	19.997	0.085
212°.2	30.041	0.119	202°.2	24.545	0.101	192°.2	19.912	0.085
212°.0	29.922	0.119	**202°.0**	24.444	0.101	**192°.0**	19.827	0.084
211°.8	29.803	0.118	201°.8	24.343	0.100	191°.8	19.743	0.084
211°.6	29.685	0.118	201°.6	24.243	0.099	191°.6	19.659	0.084
211°.4	29.567	0.118	201°.4	24.144	0.099	191°.4	19.575	0.083
211°.2	29.449	0.117	201°.2	24.045	0.099	191°.2	19.492	0.083
211°.0	29.332	0.117	**201°.0**	23.946	0.099	**191°.0**	19.409	0.083
210°.8	29.215	0.116	200°.8	23.847	0.098	190°.8	19.326	0.083
210°.6	29.099	0.116	200°.6	23.749	0.098	190°.6	19.243	0.082
210°.4	28.983	0.115	200°.4	23.651	0.098	190°.4	19.161	0.082
210°.2	28.868	0.115	200°.2	23.553	0.097	190°.2	19.079	0.082
210°.0	28.753	0.115	**200°.0**	23.456	0.097	**190°.0**	18.997	0.081
209°.8	28.638	0.114	199°.8	23.359	0.097	189°.8	18.916	0.081
209°.6	28.524	0.114	199°.6	23.262	0.096	189°.6	18.835	0.081
209°.4	28.410	0.114	199°.4	23.166	0.096	189°.4	18.754	0.081
209°.2	28.296	0.113	199°.2	23.070	0.096	189°.2	18.673	0.080
209°.0	28.183	0.113	**199°.0**	22.974	0.095	**189°.0**	18.593	0.080
208°.8	28.070	0.112	198°.8	22.879	0.095	188°.8	18.513	0.079
208°.6	27.958	0.112	198°.6	22.784	0.095	188°.6	18.434	0.079
208°.4	27.846	0.112	198°.4	22.689	0.094	188°.4	18.355	0.079
208°.2	27.734	0.112	198°.2	22.595	0.094	188°.2	18.276	0.079
208°.0	27.622	0.111	**198°.0**	22.501	0.094	**188°.0**	18.197	0.079
207°.8	27.511	0.111	197°.8	22.407	0.094	187°.8	18.118	0.078
207°.6	27.400	0.110	197°.6	22.313	0.093	187°.6	18.040	0.078
207°.4	27.290	0.110	197°.4	22.220	0.093	187°.4	17.962	0.078
207°.2	27.180	0.110	197°.2	22.127	0.092	187°.2	17.884	0.077
207°.0	27.070	0.109	**197°.0**	22.035	0.092	**187°.0**	17.807	0.077
206°.8	26.961	0.109	196°.8	21.943	0.092	186°.8	17.730	0.076
206°.6	26.852	0.109	196°.6	21.851	0.091	186°.6	17.654	0.076
206°.4	26.743	0.108	196°.4	21.760	0.091	186°.4	17.578	0.076
206°.2	26.635	0.108	196°.2	21.669	0.091	186°.2	17.502	0.076
206°.0	26.527	0.107	**196°.0**	21.578	0.090	**186°.0**	17.426	0.076
205°.8	26.420	0.107	195°.8	21.488	0.090	185°.8	17.350	0.076
205°.6	26.313	0.107	195°.6	21.398	0.090	185°.6	17.274	0.075
205°.4	26.206	0.106	195°.4	21.308	0.090	185°.4	17.199	0.075
205°.2	26.100	0.106	195°.2	21.218	0.090	185°.2	17.124	0.075
205°.0	25.994	0.106	**195°.0**	21.128	0.089	**185°.0**	17.049	
204°.8	25.888	0.106	194°.8	21.039	0.089			
204°.6	25.782	0.105	194°.6	20.950	0.088			
204°.4	25.677	0.105	194°.4	20.862	0.088			
204°.2	25.572	0.104	194°.2	20.774	0.087			
204°.0	25.468		**194°.0**	20.687				

Table VIII. *Giving the Maximum Tension or Elastic Force of Vapor of Water, for every degree from* 185° *to* 104°. *Pn. par.* 87 *page* 58, *and par.* 139 *page* 94.

Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.
185°	17.0492	.3688	158°	9.1770	.2192	131°	4.6252	.1221
184°	16.6804	.3622	157°	8.9578	.2147	130°	4.5031	.1193
183°	16.3182	.3556	156°	8.7431	.2103	129°	4.3838	.1165
182°	15.9626	.3491	155°	8.5328	.2059	128°	4.2673	.1139
181°	15.6135	.3426	154°	8.3269	.2016	127°	4.1534	.1113
180°	15.2709	.3363	153°	8.1253	.1972	126°	4.0421	.1087
179°	14.9346	.3301	152°	7.9281	.1932	125°	3.9334	.1061
178°	14.6045	.3240	151°	7.7349	.1893	124°	3.8273	.1036
177°	14.2805	.3180	150°	7.5456	.1854	123°	3.7237	.1013
176°	13.9625	.3121	149°	7.3602	.1815	122°	3.6214	.0990
175°	13.6504	.3062	148°	7.1787	.1777	121°	3.5224	.0967
174°	13.3442	.3004	147°	7.0010	.1739	120°	3.4257	.0944
173°	13.0438	.2947	146°	6.8271	.1703	119°	3.3313	.0921
172°	12.7491	.2890	145°	6.6568	.1667	118°	3.2392	.0899
171°	12.4601	.2834	144°	6.4901	.1632	117°	3.1493	.0878
170°	12.1767	.2779	143°	6.3269	.1597	116°	3.0615	.0857
169°	11.8988	.2725	142°	6.1672	.1563	115°	2.9758	.0836
168°	11.6263	.2672	141°	6.0109	.1529	114°	2.8922	.0815
167°	11.3591	.2620	140°	5.8580	.1496	113°	2.8107	.0794
166°	11.0971	.2569	139°	5.7084	.1463	112°	2.7313	.0775
165°	10.8402	.2519	138°	5.5621	.1431	111°	2.6538	.0756
164°	10.5883	.2470	137°	5.4190	.1399	110°	2.5782	.0738
163°	10.3413	.2422	136°	5.2791	.1368	109°	2.5044	.0720
162°	10.0991	.2374	135°	5.1423	.1337	108°	2.4324	.0702
161°	9.8617	.2328	134°	5.0086	.1307	107°	2.3622	.0685
160°	9.6289	.2282	133°	4.8779	.1278	106°	2.2937	.0668
159°	9.4007	.2237	132°	4.7501	.1249	105°	2.2269	.0652

Table IX. *Giving the Maximum Tension or Elastic Force of Vapor of Water, for every* 0.2 *degree from* 104° *to* 0°, *and for every degree from* 0° *to* — 31°.

Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.
104°.0	2.1617	.0128	**100°.0**	1.9178	.0115	**96°.0**	1.6981	.0103
103°.8	2.1489	.0127	99°.8	1.9063	.0115	95°.8	1.6878	.0103
103°.6	2.1362	.0127	99°.6	1.8948	.0115	95°.6	1.6775	.0103
103°.4	2.1235	.0126	99°.4	1.8833	.0114	95°.4	1.6672	.0102
103°.2	2.1109	.0126	99°.2	1.8719	.0113	95°.2	1.6570	.0102
103°.0	2.0983	.0125	**99°.0**	1.8606	.0112	**95°.0**	1.6468	.0102
102°.8	2.0858	.0124	98°.8	1.8494	.0112	94°.8	1.6366	.0101
102°.6	2.0734	.0123	98°.6	1.8382	.0111	94°.6	1.6265	.0100
102°.4	2.0611	.0123	98°.4	1.8271	.0110	94°.4	1.6165	.0099
102°.2	2.0488	.0122	98°.2	1.8161	.0110	94°.2	1.6066	.0099
102°.0	2.0366	.0122	**98°.0**	1.8051	.0109	**94°.0**	1.5967	.0098
101°.8	2.0244	.0121	97°.8	1.7942	.0109	93°.8	1.5869	.0098
101°.6	2.0123	.0120	97°.6	1.7833	.0109	93°.6	1.5771	.0097
101°.4	2.0003	.0120	97°.4	1.7724	.0108	93°.4	1.5674	.0097
101°.2	1.9883	.0119	97°.2	1.7616	.0107	93°.2	1.5577	.0097
101°.0	1.9764	.0118	**97°.0**	1.7509	.0107	**93°.0**	1.5480	.0096
100°.8	1.9646	.0118	96°.8	1.7402	.0106	92°.8	1.5384	.0095
100°.6	1.9528	.0117	96°.6	1.7296	.0106	92°.6	1.5289	.0095
100°.4	1.9411	.0117	96°.4	1.7190	.0105	92°.4	1.5194	.0094
100°.2	1.9294	.0116	96°.2	1.7085	.0104	92°.2	1.5100	.0094
100°.0	1.9178		**96°.0**	1.6981		**92°.0**	1.5006	

TABLE IX (Continued). *Giving the Maximum Tension or Elastic Force of Vapor of Water.*

Temp. Fah.	Max. Tens. Inch. Merc.	Differ-ences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differ-ences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differ-ences.
92°.0	1.5006	.0093	**81°.0**	1.0572	.0069	**70°.0**	0.7331	.0050
91°.8	1.4913	.0092	80°.8	1.0503	.0068	69°.8	0.7281	.0049
91°.6	1.4821	.0092	80°.6	1.0435	.0068	69°.6	0.7232	.0049
91°.4	1.4729	.0092	80°.4	1.0367	.0067	69°.4	0.7183	.0049
91°.2	1.4637	.0092	80°.2	1.0300	.0067	69°.2	0.7134	.0049
91°.0	1.4545	.0091	**80°.0**	1.0233	.0067	**69°.0**	0.7085	.0049
90°.8	1.4454	.0090	79°.8	1.0166	.0066	68°.8	0.7036	.0048
90°.6	1.4364	.0090	79°.6	1.0100	.0066	68°.6	0.6988	.0047
90°.4	1.4274	.0089	79°.4	1.0034	.0066	68°.4	0.6941	.0047
90°.2	1.4185	.0089	79°.2	0.9968	.0065	68°.2	0.6894	.0047
90°.0	1.4096	.0088	**79°.0**	0.9903	.0065	**68°.0**	0.6847	.0047
89°.8	1.4008	.0087	78°.8	0.9838	.0064	67°.8	0.6800	.0046
89°.6	1.3921	.0087	78°.6	0.9774	.0064	67°.6	0.6754	.0046
89°.4	1.3834	.0087	78°.4	0.9710	.0064	67°.4	0.6708	.0046
89°.2	1.3747	.0086	78°.2	0.9646	.0063	67°.2	0.6662	.0046
89°.0	1.3661	.0086	**78°.0**	0.9583	.0063	**67°.0**	0.6616	.0046
88°.8	1.3575	.0086	77°.8	0.9520	.0063	66°.8	0.6570	.0045
88°.6	1.3489	.0085	77°.6	0.9457	.0062	66°.6	0.6525	.0045
88°.4	1.3404	.0085	77°.4	0.9395	.0062	66°.4	0.6480	.0045
88°.2	1.3319	.0084	77°.2	0.9333	.0061	66°.2	0.6435	.0044
88°.0	1.3235	.0083	**77°.0**	0.9272	.0061	**66°.0**	0.6391	.0044
87°.8	1.3152	.0083	76°.8	0.9211	.0061	65°.8	0.6347	.0044
87°.6	1.3069	.0083	76°.6	0.9150	.0061	65°.6	0.6303	.0043
87°.4	1.2986	.0082	76°.4	0.9089	.0061	65°.4	0.6260	.0043
87°.2	1.2904	.0082	76°.2	0.9028	.0060	65°.2	0.6217	.0043
87°.0	1.2822	.0081	**76°.0**	0.8968	.0059	**65°.0**	0.6174	.0043
86°.8	1.2741	.0081	75°.8	0.8909	.0059	64°.8	0.6131	.0043
86°.6	1.2660	.0080	75°.6	0.8850	.0058	64°.6	0.6088	.0042
86°.4	1.2580	.0080	75°.4	0.8792	.0058	64°.4	0.6046	.0042
86°.2	1.2500	.0079	75°.2	0.8734	.0058	64°.2	0.6004	.0042
86°.0	1.2421	.0079	**75°.0**	0.8676	.0058	**64°.0**	0.5962	.0041
85°.8	1.2342	.0079	74°.8	0.8618	.0058	63°.8	0.5921	.0041
85°.6	1.2263	.0078	74°.6	0.8560	.0057	63°.6	0.5880	.0041
85°.4	1.2185	.0078	74°.4	0.8503	.0057	63°.4	0.5839	.0041
85°.2	1.2107	.0077	74°.2	0.8446	.0056	63°.2	0.5798	.0040
85°.0	1.2030	.0077	**74°.0**	0.8390	.0056	**63°.0**	0.5758	.0040
84°.8	1.1953	.0076	73°.8	0.8334	.0055	62°.8	0.5718	.0040
84°.6	1.1877	.0076	73°.6	0.8279	.0055	62°.6	0 5678	.0040
84°.4	1.1801	.0075	73°.4	0.8224	.0055	62°.4	0.5638	.0039
84°.2	1.1726	.0075	73°.2	0.8169	.0055	62°.2	0.5599	.0039
84°.0	1.1651	.0075	**73°.0**	0.8114	.0054	**62.°0**	0.5560	.0039
83°.8	1.1576	.0074	72°.8	0.8060	.0054	61°.8	0.5521	.0039
83°.6	1.1502	.0074	72°.6	0.8006	.0054	61°.6	0.5482	.0039
83°.4	1.1428	.0074	72°.4	0.7952	.0054	61°.4	0.5443	.0038
83°.2	1.1354	.0073	72°.2	0.7898	.0053	61°.2	0.5405	.0038
83°.0	1.1281	.0073	**72°.0**	0.7845	.0053	**61°.0**	0.5367	.0038
82°.8	1.1208	.0072	71°.8	0.7792	.0052	60°.8	0.5329	.0038
82°.6	1.1136	.0072	71°.6	0.7740	.0052	60°.6	0.5291	.0037
82°.4	1.1064	.0071	71°.4	0.7688	.0052	60°.4	0.5254	.0037
82°.2	1.0993	.0071	71°.2	0.7636	.0051	60°.2	0.5217	.0037
82°.0	1.0922	.0071	**71°.0**	0.7585	.0051	**60°.0**	0.5180	.0037
81°.8	1.0851	.0070	70°.8	0.7534	.0051	59°.8	0.5143	.0036
81°.6	1.0781	.0070	70°.6	0.7483	.0051	59°.6	0.5107	.0036
81°.4	1.0711	.0070	70°.4	0.7432	.0051	59°.4	0.5071	.0036
81°.2	1.0641	.0069	70°.2	0.7381	.0050	59°.2	0.5035	.0036
81°.0	1.0572		70°.0	0.7331		59°.0	0.4999	

TABLE IX. (Continued). *Giving the Maximum Tension or Elastic Force of Vapor of Water.*

Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.
59°.0	0.4999	.0035	**48°.0**	0.3351	.0025	**37.°0**	0.2205	.0017
58°.8	0.4964	.0035	47°.8	0.3326	.0025	36°.8	0.2188	.0017
58°.6	0.4929	.0035	47°.6	0.3301	.0025	36°.6	0.2171	.0017
58°.4	0.4894	.0035	47°.4	0.3276	.0024	36°.4	0.2154	.0017
58°.2	0.4859	.0035	47°.2	0.3252	.0024	36°.2	0.2137	.0017
58°.0	0.4824	.0034	**47°.0**	0.3228	.0024	**36°.0**	0.2120	.0016
57°.8	0.4790	.0034	46°.8	0.3204	.0024	35°.8	0.2104	.0016
57°.6	0.4756	.0034	46°.6	0.3180	.0024	35°.6	0.2088	.0016
57°.4	0.4722	.0034	46°.4	0.3156	.0024	35°.4	0.2072	.0016
57°.2	0.4688	.0033	46°.2	0.3132	.0023	35°.2	0.2056	.0016
57°.0	0.4655	.0033	**46°.0**	0.3109	.0023	**35°.0**	0.2040	.0016
56°.8	0.4622	.0033	45°.8	0.3086	.0023	34°.8	0.2024	.0016
56°.6	0.4589	.0033	45°.6	0.3063	.0023	34°.6	0.2008	.0016
56°.4	0.4556	.0033	45°.4	0.3040	.0023	34°.4	0.1992	.0016
56°.2	0.4523	.0032	45°.2	0.3017	.0023	34°.2	0.1976	.0016
56°.0	0.4491	.0032	**45°.0**	0.2994	.0022	**34°.0**	0.1960	.0016
55°.8	0.4459	.0032	44°.8	0.2972	.0022	33°.8	0.1944	.0015
55°.6	0.4427	.0032	44°.6	0.2950	.0022	33°.6	0.1929	.0015
55°.4	0.4395	.0032	44°.4	0.2928	.0022	33°.4	0.1914	.0015
55°.2	0.4363	.0032	44°.2	0.2906	.0022	33°.2	0.1899	.0015
55°.0	0.4331	.0032	**44°.0**	0.2884	.0022	**33°.0**	0.1884	.0015
54°.8	0.4299	.0031	43°.8	0.2862	.0022	32°.8	0.1869	.0015
54°.6	0.4268	.0031	43°.6	0.2840	.0022	32°.6	0.1854	.0015
54°.4	0.4237	.0030	43°.4	0.2818	.0021	32°.4	0.1840	.0015
54°.2	0.4207	.0030	43°.2	0.2797	.0021	32°.2	0.1825	.0015
54°.0	0.4177	.0030	**43°.0**	0.2776	.0021	**32°.0**	0.1811	.0015
53°.8	0.4147	.0030	42°.8	0.2755	.0021	31°.8	0.1796	.0015
53°.6	0.4117	.0030	42°.6	0.2734	.0021	31°.6	0.1781	.0015
53°.4	0.4087	.0030	42°.4	0.2713	.0021	31°.4	0.1766	.0015
53°.2	0.4057	.0029	42°.2	0.2692	.0020	31°.2	0.1751	.0015
53°.0	0.4028	.0029	**42°.0**	0.2672	.0020	**31°.0**	0.1736	.0014
52°.8	0.3999	.0029	41°.8	0.2652	.0020	30°.8	0.1722	.0014
52°.6	0.3970	.0029	41°.6	0.2632	.0020	30°.6	0.1708	.0014
52°.4	0.3941	.0029	41°.4	0.2612	.0020	30°.4	0.1694	.0014
52°.2	0.3912	.0029	41°.2	0.2592	.0020	30°.2	0.1680	.0014
52°.0	0.3883	.0028	**41°.0**	0.2572	.0020	**30°.0**	0.1666	.0014
51°.8	0.3855	.0028	40°.8	0.2552	.0019	29°.8	0.1652	.0014
51°.6	0.3827	.0028	40°.6	0.2533	.0019	29°.6	0.1638	.0014
51°.4	0.3799	.0028	40°.4	0.2514	.0019	29°.4	0.1624	.0014
51°.2	0.3771	.0028	40°.2	0.2495	.0019	29°.2	0.1610	.0014
51°.0	0.3743	.0027	**40°.0**	0.2476	.0019	**29°.0**	0.1596	.0013
50°.8	0.3716	.0027	39°.8	0.2457	.0019	28°.8	0.1583	.0013
50°.6	0.3689	.0027	39°.6	0.2438	.0019	28°.6	0.1570	.0013
50°.4	0.3662	.0027	39°.4	0.2419	.0019	28°.4	0.1557	.0013
50°.2	0.3635	.0027	39°.2	0.2400	.0018	28°.2	0.1544	.0013
50°.0	0.3608	.0027	**39°.0**	0.2382	.0018	**28°.0**	0.1531	.0013
49°.8	0.3581	.0026	38°.8	0.2364	.0018	27°.8	0.1518	.0013
49°.6	0.3555	.0026	38°.6	0.2346	.0018	27°.6	0.1505	.0013
49°.4	0.3529	.0026	38°.4	0.2328	.0018	27°.4	0.1492	.0013
49°.2	0.3503	.0026	38°.2	0.2310	.0018	27°.2	0.1479	.0013
49°.0	0.3477	.0026	**38°.0**	0.2292	.0018	**27°.0**	0.1466	.0012
48°.8	0.3451	.0025	37°.8	0.2274	.0018	26°.8	0.1454	.0012
48°.6	0.3426	.0025	37°.6	0.2256	.0017	26°.6	0.1442	.0012
48°.4	0.3401	.0025	37°.4	0.2239	.0017	26°.4	0.1430	.0012
48°.2	0.3376	.0025	37°.2	0.2222	.0017	26°.2	0.1418	.0012
48°.0	0.3351		37°.0	0.2205		**26°.0**	0.1406	

TABLE IX. (Continued). *Giving the Maximum Tension or Elastic Force of Vapor of Water.*

Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.	Temp. Fah.	Max. Tens. Inch. Merc.	Differences.
26°.0	0.1406		15°.0	0.0858		4°.0	0.0520	
25°.8	0.1394	.0012	14°.8	0.0850	.0008	3°.8	0.0515	.0005
25°.6	0.1382	.0012	14°.6	0.0842	.0008	3°.6	0.0510	.0005
25°.4	0.1370	.0012	14°.4	0.0834	.0008	3°.4	0.0505	.0005
25°.2	0.1358	.0012	14°.2	0.0826	.0008	3°.2	0.0500	.0005
25°.0	0.1346	.0012	14°.0	0.0818	.0008	3°.0	0.0495	.0005
24°.8	0.1334	.0012	13°.8	0.0810	.0008	2°.8	0.0490	.0005
24°.6	0.1322	.0012	13°.6	0.0803	.0007	2°.6	0.0485	.0005
24°.4	0.1310	.0012	13°.4	0.0796	.0007	2°.4	0.0481	.0004
24°.2	0.1299	.0011	13°.2	0.0789	.0007	2°.2	0.0477	.0004
24°.0	0.1288	.0011	13°.0	0.0782	.0007	2°.0	0.0473	.0004
23°.8	0.1277	.0011	12°.8	0.0775	.0007	1°.8	0.0469	.0004
23°.6	0.1266	.0011	12°.6	0.0768	.0007	1°.6	0.0465	.0004
23°.4	0.1255	.0011	12°.4	0.0761	.0007	1°.4	0.0461	.0004
23°.2	0.1244	.0011	12°.2	0.0754	.0007	1°.2	0.0457	.0004
23°.0	0.1233	.0011	12°.0	0.0747	.0007	1°.0	0.0453	.0004
22°.8	0.1222	.0011	11°.8	0.0740	.0007	0°.8	0.0449	.0004
22°.6	0.1211	.0011	11°.6	0.0733	.0007	0°.6	0.0445	.0004
22°.4	0.1200	.0011	11°.4	0.0726	.0007	0°.4	0.0441	.0004
22°.2	0.1189	.0011	11°.2	0.0719	.0007	0°.2	0.0437	.0004
22°.0	0.1178	.0011	11°.0	0.0713	.0006	0°.0	0.0433	.0004
21°.8	0.1168	.0010	10°.8	0.0707	.0006	0°	0.0433	
21°.6	0.1158	.0010	10°.6	0.0701	.0006	—1°	0.0413	.0020
21°.4	0.1148	.0010	10°.4	0.0695	.0006	2°	0.0394	.0019
21°.2	0.1138	.0010	10°.2	0.0689	.0006	3°	0.0376	.0018
21°.0	0.1128	.0010	10°.0	0.0683	.0006	4°	0.0360	.0016
20°.8	0.1118	.0010	9°.8	0.0677	.0006	5°	0.0344	.0016
20°.6	0.1108	.0010	9°.6	0.0671	.0006	—6°	0.0328	.0016
20°.4	0.1098	.0010	9°.4	0.0665	.0006	7°	0.0313	.0015
20°.2	0.1088	.0010	9°.2	0.0659	.0006	8°	0.0299	.0014
20°.0	0.1078	.0010	9°.0	0.0653	.0006	9°	0.0285	.0014
19°.8	0.1068	.0010	8°.8	0.0647	.0006	10°	0.0272	.0013
19°.6	0.1058	.0010	8°.6	0.0641	.0006	—11°	0.0259	.0013
19°.4	0.1048	.0010	8°.4	0.0635	.0006	12°	0.0247	.0012
19°.2	0.1039	.0009	8°.2	0.0629	.0006	13°	0.0236	.0011
19°.0	0.1030	.0009	8°.0	0.0623	.0006	14°	0.0225	.0011
18°.8	0.1021	.0009	7°.8	0.0617	.0006	15°	0.0215	.0010
18°.6	0.1012	.0009	7°.6	0.0611	.0006	—16°	0.0205	.0010
18°.4	0.1003	.0009	7°.4	0.0605	.0006	17°	0.0196	.0009
18°.2	0.0994	.0009	7°.2	0.0600	.0005	18°	0.0187	.0009
18°.0	0.0985	.0009	7°.0	0.0595	.0005	19°	0.0178	.0009
17°.8	0.0976	.0009	6°.8	0.0590	.0005	20°	0.0170	.0008
17°.6	0.0967	.0009	6°.6	0.0585	.0005	—21°	0.0162	.0008
17°.4	0.0958	.0009	6°.4	0.0580	.0005	22°	0.0154	.0008
17°.2	0.0949	.0009	6°.2	0.0575	.0005	23°	0.0147	.0007
17°.0	0.0940	.0009	6°.0	0.0570	.0005	24°	0.0140	.0007
16°.8	0.0931	.0009	5°.8	0.0565	.0005	25°	0.0133	.0007
16°.6	0.0922	.0009	5°.6	0.0560	.0005	—26°	0.0127	.0006
16°.4	0.0914	.0008	5°.4	0.0555	.0005	27°	0.0121	.0006
16°.2	0.0906	.0008	5°.2	0.0550	.0005	28°	0.0115	.0006
16°.0	0.0898	.0008	5°.0	0.0545	.0005	29°	0.0110	.0005
15°.8	0.0890	.0008	4°.8	0.0540	.0005	30°	0.0105	.0005
15°.6	0.0882	.0008	4°.6	0.0535	.0005	31°	0.0100	.0005
15°.4	0.0874	.0008	4°.4	0.0530	.0005			
15°.2	0.0866	.0008	4°.2	0.0525	.0005			
15°.0	0.0858	.0008	4°.0	0.0520	.0005			